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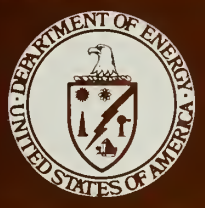

Site Characterization Progress Report: Yucca Mountain, Nevada

April 1, 1994 - September 30, 1994

Number 11

March 1995

U.S. Department of Energy
Office of Civilian Radioactive Waste Management

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Washington, DC 20585

March 17, 1995

NOTE TO READERS:

A great deal was achieved during the reporting period despite the constrained funding that was available for fiscal year 1994. The principal achievement included restructuring the Program to provide a new approach both to the evaluation of the site, with respect to its ability to be developed as a repository, and to the licensing of the proposed Yucca Mountain site. One important accomplishment of this reporting period, and the key to our progress in the future, was the increase in the level of funding for the program that was supported by the Administration and Congress. Most of the additional funding received for fiscal year 1995 was allocated to the Yucca Mountain site characterization project.

The new Program Approach was developed to bring the program of work at Yucca Mountain into conformity with the fiscal year 1995 funding allocation and out-year expectations. This restructured program provides an approach to the site suitability evaluation process that ensures efficient, measurable progress towards the evaluation of the suitability of the site and, if the site is suitable, provides the basis for proceeding with the Environmental Impact Statement, Site Recommendation Report to the President, License Application, and construction of a repository.

During the reporting period, the Yucca Mountain Site Characterization Project made significant progress in surface-based testing, advanced conceptual design, performance assessment, planning, licensing support system development activities, and construction of the Exploratory Studies Facility.

The Program will continue to focus on implementation of the Program Approach. Progress will be reported in Progress Report #12 in terms of the new Program Approach as the emphasis of the site characterization work will be on obtaining the information necessary to support a Technical Site Suitability Evaluation.

Sincerely,

Daniel A. Dreyfus, Director
Office of Civilian Radioactive
Waste Management

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FOREWORD

For ease of use of this document, the reader should note that the Executive Summary provides a summary of major decisions, activities, accomplishments, and issues of interest during the reporting period. Key events that occurred after the close of the reporting period, but prior to printing this report, are included at the end of the Executive Summary.

This report has been reorganized to present the discussion of progress during the reporting period in a more clear and logical manner. Chapter 1, Introduction, contains background information to assist the reader in understanding the current status of the program. Chapter 2, Programmatic Activities, contains progress in activities necessary to focus, evaluate, plan, control, and ensure the quality of the site characterization program. Chapter 3, Site Programs, contains progress of site characterization studies and activities. Chapter 4, Repository Design, contains progress of design activities related to repository and seals design. Chapter 5, Waste Package, contains progress of waste package design activities. Chapter 6, Performance Assessment, contains progress made in analyses and modeling necessary to evaluate total system performance. Chapter 7, Exploratory Studies Facility Design and Construction, contains progress of work performed on Design Packages, seismic design, and construction of the Exploratory Studies Facility.

The report begins with a Note to Readers that summarizes major achievements during the reporting period. For general interest a reader may wish to first review the Note to Readers, Executive Summary, and Introduction prior to turning to the more detailed discussion of technical studies and activities presented in Chapters 3 through 7.

Information in this Progress Report is conveyed in a summary form for convenient information exchange. Additional specific information is available in the reference documents listed in Appendix F. A list of Acronyms, Abbreviations, and Symbols is contained in Appendix G to further assist the reader.

Executive Summary

Site characterization activities at Yucca Mountain, Nevada, from April 1, 1994, through September 30, 1994. Eleventh in a series reported in accordance with the requirements of Section 113(b)(3) of the Nuclear Waste Policy Act of 1982, as amended, and 10 CFR 60.18(g).

During the second half of fiscal year 1994, the U.S. Department of Energy developed and refined the Proposed Program Approach to restructure the Civilian Radioactive Waste Management Program. This approach, hereinafter referred to as the Program Approach, stimulated and directed many of the activities of the Yucca Mountain Site Characterization Project during this reporting period. The Program, which is evaluating Yucca Mountain as a possible site for a geologic repository for the permanent disposal of spent nuclear fuel and high-level radioactive waste, advanced in several critical areas. These included programmatic activities such as development of the Program Approach and the Five-Year Plan, investigation and analysis of the site, design and construction of the Exploratory Studies Facility, and continuation of the focused Advanced Conceptual Design for the repository. The following sections highlight accomplishments in each major area. Specific details relating to all Project activities and reports generated are presented in the main body of the report.

Programmatic Activities

In part, the Program Approach was developed to bring work at Yucca Mountain into conformity with the fiscal year 1995 budget request and out-year funding expectations and to develop realistic estimates of schedules and costs. In addition, the approach was formulated to ensure efficient, measurable progress toward determining the suitability of the Yucca Mountain site for a permanent repository and, if the site is suitable, provide the basis for proceeding with the Environmental Impact Statement, Site Recommendation Report, License Application, and construction of a repository.

Five-Year Plan

The Program Approach provided the basis for a long-range planning effort that will be reflected in the Civilian Radioactive Waste Management Program Plan for the repository program that the Department is currently preparing. A major input to this overall plan is the Five-Year Plan for the Yucca Mountain Site Characterization Project, which the Department began preparing during this reporting period.

The Five-Year Plan will describe the activities needed to implement the strategies established in the Program Approach for evaluating site suitability, completing the National Environmental Policy Act process, and developing a License Application. The Five-Year Plan will also clearly define progress against interim milestones and products, and will clarify relationships among activities, products, and budgets.

By implementing the Program Approach and the other strategies outlined in the Five-Year Plan, the Department will evaluate the technical suitability of the Yucca Mountain site by the end of fiscal year 1998, using a step-wise assessment of compliance with each 10 CFR Part 960 siting guideline, or groups of guidelines. In this evaluation, the Department will ascertain whether the postclosure guidelines of 10 CFR Part 960 and those preclosure guidelines related to radiological safety and technical feasibility are satisfied. The 1998 evaluation will be supported by a Total System Performance Assessment that will include subsystem interactions. The preclosure guidelines related to environmental quality, socioeconomic impact, and transportation will be evaluated as a part of the determination of overall site suitability expected by the end of fiscal year 2000. This evaluation will use information developed to support the National Environmental Policy Act process and the preparation of a Draft Environmental Impact Statement to be released for public comment in 1998. Also in 2000, the Department expects to deliver a Final Environmental Impact Statement and, if the site is found suitable, a Site Recommendation Report to the President. In the following year, if the President recommends the site and Congress approves it, if necessary, the Department will submit a License Application for the construction of the repository to the U.S. Nuclear Regulatory Commission and be prepared to support the Commission's legal obligation to decide on the repository construction authorization within three years of the application date.

Five-Year Plan Goals

FY 1998 - Evaluate technical suitability of Yucca Mountain
- Draft Environmental Impact Statement

FY 2000 - Determine overall suitability of Yucca Mountain
- Final Environmental Impact Statement
- Site Recommendation Report

FY 2001 - License Application

To support the Five-Year Plan and the new Program Approach, the Project completed drafts of fiscal year 1995 Technical Implementation Plans for most of the Project Work Breakdown Structure elements. These plans include a clear implementation of Project priorities, a mapping of the proposed budget to these priorities, detailed work scope statements, and proposed milestones and deliverables including comprehensive completion criteria.

Regulatory Activities

Reflected in the Five-Year Plan milestones is the Department's process of sequential evaluation of site suitability, which calls for the evaluation of individual guideline conditions, or groups of guidelines, as site characterization data, analyses, facility designs, and nongeotechnical data become available. This process was developed with input from the public and oversight groups at numerous meetings and workshops. In addition, on April 25, 1994, a Notice of Inquiry was published in the Federal

After careful consideration, the Department of Energy decided to use 10 CFR Part 960, without modification, to evaluate suitability.

Register requesting the views of members of the public regarding the process for evaluating site suitability and on August 4, 1994, a Federal Register Notice was published announcing the Department's decision to use 10 CFR Part 960. The August 4, 1994, Notice also requested public comments on a draft description of the process for evaluating the suitability of the Yucca Mountain site. The process provides for predecisional public involvement at key points in the evaluation sequence and external peer review of technical reports that will be used to assess compliance with each guideline.

Also during this reporting period, the existing Annotated Outline for the License Application was revised in response to the major program redirection represented in the Program Approach. The Annotated Outline was converted from a contractor document into a Department of Energy document, renamed the Mined Geologic Disposal System License Application Annotated Outline, and is now scheduled to be transmitted to the Commission in March 1995. A draft licensing strategy consistent with the Program Approach and the multi-purpose canister was developed for incorporation in the License Application Annotated Outline.

Department and Commission staff will meet during the next reporting period to discuss staff concerns about the Department's proposed methods for assessing seismic hazards.

The Issue Resolution Process was continued through Technical Exchanges with Commission staff and topical report development by the Department. This process is intended to help identify, clarify, and resolve technical and regulatory issues raised during site characterization. The focus in this period was on the issues of substantially complete containment, ground-water travel time, the definition of the boundaries of the Engineered Barrier System, extreme erosion analysis, and seismic hazards. Commission staff have agreed in principle with the Department's new performance goal for demonstrating compliance with the substantially complete containment provisions of 10 CFR Part 60. Technical discussions are continuing, with the Department providing supplemental responses to questions raised by Commission staff. In other interactions, the Department submitted its general approach for calculating ground-water travel time to evaluate compliance with the performance objective for the geologic setting in 10 CFR Part 60 and with the disqualifying condition for geohydrology in 10 CFR Part 960. The view presented by the Department is that travel time is a distribution of water particle transport times between the disturbed zone and the accessible environment, and that the significance of travel times less than 1000 years should be evaluated from a total system perspective. Commission staff generally agreed with the approach and raised a number of questions to be discussed in a November 1994 Technical Exchange. The Department also agreed with the Commission definition that the Engineered Barrier System does not extend into the host rock.

The Department received the results of Commission staff review of the report, entitled "Evaluation of the Potentially Adverse Condition 'Evidence of Extreme Erosion during the Quaternary Period' at Yucca Mountain" on August 22, 1994. Both in their letter and in subsequent discussions, Commission staff have made it clear that a broader approach for addressing this potentially adverse condition is required. On September 7, 1994, Commission

staff provided a letter stating that the topical report entitled "Topical Report YMP/TR-002-NP: Methodology to Assess Fault Displacement and Vibratory Ground Motion at Yucca Mountain" did not meet the review criteria of their Topical Report Review Plan. During the next reporting period, Department and Commission staff will participate in Technical Exchanges to resolve staff concerns on the Department's extreme erosion approach and discuss the methodology to assess fault displacement and vibratory ground motion at Yucca Mountain.

Resolution of Site Characterization Analysis open items is being consolidated with the Issue Resolution process. At the end of this reporting period, 85 open items were closed and 113 remain open. Most of the remaining open items need data from site characterization activities to resolve.

The Energy Policy Act of 1992 directed the U.S. Environmental Protection Agency, based on recommendations of the National Academy of Sciences, to promulgate public health and safety standards for a repository at Yucca Mountain. At their request, the Department provided the National Academy of Sciences its recommendation regarding a standard for Yucca Mountain during this reporting period.

The Department of Energy provided the National Academy of Sciences its recommendation regarding a health and safety standard for Yucca Mountain.

Quality Assurance

Notable progress has been made in the transition to the revised Quality Assurance Program as described in the new Quality Assurance Requirements and Description. Quality Assurance programs, updated to the revised program, were accepted by the Department for the U.S. Geological Survey, Technical and Management Support Services contractor, Sandia National Laboratories, and Lawrence Livermore National Laboratory. Audits and surveillances were conducted to verify compliance with and to determine effectiveness of the applicable requirements of the Civilian Radioactive Waste Management Quality Assurance Program. All areas audited indicated satisfactory performance with the exception of the Civilian Radioactive Waste Management System Management and Operating Contractor's design control program. The Department received a letter from the Commission identifying issues related to the Management and Operating Contractor's Quality Assurance Program and the Department's role in the oversight of their Program. A response was prepared outlining actions to be taken by the Department to ensure effective implementation by the Management and Operating Contractor and effective oversight by the Department. The Office of Quality Assurance will continue to monitor progress to ensure corrective actions are preventing recurrence of problems through verifications, audits, and surveillances.

The Department of Energy's Office of Quality Assurance will verify that corrective actions are effective in preventing recurrence of problems.

Waste Isolation Evaluations and Test Interference Evaluations were consolidated through the Determination of Importance process. This process integrates the impact assessment conclusions into a single set of Quality Assurance requirements for conducting an activity. The first Determination of Importance Evaluations were conducted for surface-based activities and these evaluations were produced for several elements of the Exploratory Studies Facility.

Project Integration

Two activities accomplished during this reporting period will be used to help integrate technical information and make it available to investigators and oversight groups. First, work has begun to gather all available stratigraphic and structural information at Yucca Mountain and create a geologic framework three-dimensional model. This model will include more data and extend to wider boundaries than previous efforts.

The second effort accumulates Project stratigraphic data into a compendium that will summarize stratigraphic units, include lithologic logs for each borehole, and provide guidance on Project-approved nomenclature. The compendium will be a source of information for investigators, modelers, and oversight groups.

Program Outreach

Public outreach activities continued, including tours, informational materials, and meetings to provide current information on site characterization progress. With the beginning of assembly of the tunnel boring machine, public informational materials on the machine, its purpose, and its operation were developed and presented.

Grant to the National Urban Coalition for the "Say Yes to a Youngster's Future" program awarded by Yucca Mountain Site Characterization Project in September.

In September, the Project awarded a grant to the National Urban Coalition for the "Say Yes to a Youngster's Future" program to be conducted in seven elementary schools in West Las Vegas, Nevada, in conjunction with two Family Learning Centers. The program will be implemented in Clark County Schools and by working with the African Americans for Energy Awareness.

Site Investigations and Analyses

In line with the Program Approach, site investigations and performance assessment activities at Yucca Mountain will focus on activities to support a determination on technical site suitability in fiscal year 1998. The Project began to consolidate work scopes for study plans outlining site characterization activities during this reporting period. The activity will evaluate whether study plans as yet unwritten are indeed required, or whether the work could reasonably be combined under other existing study plans or results reported in other ways.

Site Programs

The Department continued to make considerable progress in surface-based testing activities. These included ongoing geological investigations that have provided information being used to design the Exploratory Studies Facility, scientific studies of the saturated and unsaturated zones, and tests evaluating the waste package environment.

Rock characteristics data and the results of laboratory geotechnical analyses were provided to those designing the Exploratory Studies Facility. Radial borehole and hydrochemistry tests began in the first test alcove excavated in the Exploratory Studies Facility. Also, the Starter Tunnel and the test alcove were monitored for perched water without any being detected.

Preparations were finalized for the saturated zone pumping studies in the C-well complex to be conducted in fiscal year 1995. This study will provide information that will be used to predict movement of radionuclides in the saturated zone. The grouting technique that will be used to instrument the boreholes for pneumatic measurements to be made this winter was successfully tested. Air-permeability tests were conducted in UE-25 UZ#16 and USW NRG-7a, and gas phase geochemical sampling was conducted in UE-25 UZ#16. Permeability values covered a large range, and statistical analysis showed no direct correlation between fracture density and permeability, indicating that flow systems may be more complicated than present flow models suggest.

Climatology investigations continued and the results were used to increase confidence in the regional climate modeling code. That work demonstrates that there is reasonable agreement between model results and the observed present-day climate. Preliminary results of geochronology studies indicate sites of past water discharge south of Yucca Mountain were active as recently as 12,000 years ago. This activity is at least an order of magnitude younger than previous estimates. These results will be important in evaluating possible responses of the regional hydrology to future climate change.

Drilling of USW UZ-14 was completed in May 1994 to a total depth of 2230 feet (680 m). During drilling, perched water was encountered above the basal vitrophyre of the Topopah Spring Member of the Paintbrush Tuff. Perched water has also been found below the basal vitrophyre at USW SD-9 and USW NRG-7a (two nearby boreholes situated along the alignment of the North Ramp and main drift of the Exploratory Studies Facility). Fractures containing free water were encountered above and below the perched water in USW UZ-14 but the matrix surrounding these fractures did not appear visually to be saturated. The setting and proximity of all these boreholes suggest that south to southeasterly lateral flow is a more likely mechanism than vertical percolation for explaining the accumulation of perched water in the area of the North Ramp of the Exploratory Studies Facility.

South to southeasterly lateral flow is a more likely mechanism than vertical percolation for explaining the accumulation of perched water in the area of the North Ramp of the Exploratory Studies Facility.

During the reporting period, chlorine-36 values were measured in samples collected from several soil profiles exposed at the UE-25 NRG#5 drill pad. At this location, soil thicknesses from surface to bedrock ranged from a few centimeters up to three meters. All 19 soil samples analyzed had chlorine-36 values considerably above natural background, indicating the possible presence of chlorine-36 from global atmospheric weapons testing fallout and hence recent meteoric water at depths up to three meters. These findings may be relevant to the issue of the origin and stability of perched water underlying Yucca Mountain insofar as they may indicate conditions under which fracture flow is initiated. There is always a potential for contamination of drilling equipment and this leads to uncertainties in interpreting these results. Further investigation in fiscal year 1995 will determine the depth at which the elevated chlorine-36 values are present and correlate the findings with lithology and structural features.

Investigations of chlorine-36 found in perched water may lead to determinations on origin and stability of perched water underlying Yucca Mountain.

Various hydrologic test data from Drillhole USW G-2 were reviewed and water-level measurements were made in USW NRG-7, USW SD-9, and USW UZ-14. These activities have provided additional insights into the "large hydraulic gradient" in an area northwest of Yucca Mountain. It has been suggested that the gradient could reflect a series of stepped low-permeability surfaces, or alternatively, a perched zone may exist that was incorrectly interpreted as an extension of the static water level, in which case the existence of a steep gradient would be in question.

The results of a comprehensive study of neptunium sorption onto Yucca Mountain tuffs in ground water from the Yucca Mountain area were compiled. A major finding that neptunium sorbs strongly to calcite is extremely important because it could indicate significant retardation of neptunium transport through fractures. These findings were incorporated into a neptunium sorption data base that will be used in performance assessment calculations and sensitivity analyses studies of radionuclide transport through Yucca Mountain tuffs.

Neptunium sorbs strongly to calcite and could indicate significant retardation of neptunium transport through fractures.

As part of the Systematic Drilling Program, two drillholes were cored: USW SD-9 and USW SD-12. These drillholes are located, respectively, about one-third and two-thirds of the way from north to south along the main Exploratory Studies Facility drift. Drillhole USW SD-9 was completed on September 23, 1994, to a total depth of 2230 feet (680 m) into rocks belonging to the Crater Flat Tuff. The drillhole penetrated approximately 350 feet (107 m) into the saturated zone, meeting the 300-foot

Downhole video examination in USW SD-9 showed perched water influx from a fracture at about 1350 feet (411 m).

(91-m) penetration requirement of the Site Characterization Plan. Drilling of the hole began May 17, 1994. Perched water was encountered at about 1353 feet (412 m) in July; drilling was temporarily suspended at a depth of 1489 feet (454 m) because of continuing inflow of water. Downhole video examination suggested that the zone of influx was restricted to a flowing fracture near 1350 feet (411 m). Drilling resumed and water was encountered again at about 1800 feet (549 m), which is consistent with the regional static water level in this portion of Yucca Mountain.

Drillhole USW SD-12 was cored to a temporary depth of 1435 feet (437 m), well below the intended depth of the Exploratory Studies Facility Main Test Level and of sufficient depth to provide data for immediate design requirements. This hole penetrated the basal contact of the Topopah Spring Member of the Paintbrush Tuff with the underlying tuffaceous beds of Calico Hills. Drilling was temporarily suspended pending procurement of replacement pipe to resolve continuing problems with the mechanical integrity of the dual-wall drill pipe.

Several activities yielded information on faults within the site area. The Geophysics Integration Task Force focused heavily on the analyses of geophysical data on the orientation of the Ghost Dance fault down to repository depth to support design of the Exploratory Studies Facility. Geologic maps of a portion of the Ghost Dance fault and Sundance fault area were completed. The vertical seismic profile developed at 1000 feet (305 m) from borehole USW WT-2 clearly shows that Ghost Dance fault is a system of faults in a zone at least several hundred feet wide and extending to a depth of at least 1000 feet (305 m). Scientists continued to examine the history of known or suspected Quaternary faults. Slip rates were determined for Stagecoach Road, Bow Ridge, and Windy Wash faults. Bow Ridge fault crosses the Exploratory Studies Facility North Ramp and shows evidence of a low but persistent level of late Quaternary activity. Slip rates are 0.001 to 0.003 millimeters per year. Studies in Midway Valley have resulted in a conclusion that no significant late Quaternary faults are present at the proposed site for repository surface facilities.

No significant late Quaternary faults are present at the proposed surface facility site in Midway Valley.

A report entitled "Status of Volcanism Studies for the Yucca Mountain Site Characterization Program," describing volcanism work from 1978 to May 1994 was in preparation. The report presents the results of field, geochronology, and geochemistry data for Miocene and younger basaltic centers of the Yucca Mountain region. The results presented in this report provided the basis for a presentation to the Nuclear Regulatory Commission Advisory Committee on Nuclear Waste in April 1994 on the characterization of volcanic features, probability studies, and effects studies. The report will be published and released during the next reporting period.

Performance Assessment

Several analyses (referred to as mini Total System Performance Assessments) were completed to update and enhance the performance assessments performed during the second iteration of the Total System Performance Assessment for Yucca Mountain. This assessment, entitled "Total System Performance Assessment - 1993," was published in March 1994. These new mini assessments address specific issues raised during and following the completion of the Total System Performance Assessment - 1993 and serve as precursors for the more complete analyses to be conducted during fiscal year 1995. The goal was to analyze the impacts of conservative assumptions in the waste package and Engineered Barrier System used in previous performance assessments on predicted performance of subsystems and the total system.

Mini total system performance assessments are used to quickly address specific issues so that more complete analyses can be developed.

In other performance assessment activities, the Department developed an approach to calculating ground-water travel time to evaluate compliance with regulatory requirements in 10 CFR Part 60 and the Department's general siting guidelines in 10 CFR Part 960. The essence of the approach is that pre-waste-emplacement ground-water travel time is considered to be a distribution that defines the likelihood of water particles reaching the accessible environment at a specific time. Following the general approach development, a more detailed approach is under development by a multidiscipline team.

The Department expects that preliminary results of ground-water travel time will be available by the end of fiscal year 1995, and the significance of travel times less than 1000 years assessed in fiscal year 1996. The second iteration of ground-water travel time evaluations should be completed in fiscal year 1997 for use in the Department's evaluation of technical site suitability.

Design and Construction Activities

The most notable activity during this period was the startup of the tunnel boring machine and the beginning of the first phase of its checkout. The tunnel boring machine was assembled and operational testing was completed. The machine was moved to the rock face at the end of the Starter Tunnel, assembled systems were tested, the tunnel face was smoothed to bring the cutter head in full contact with the back wall of the tunnel, and an additional 40 feet (12 m) was bored.

The tunnel boring machine completed operational testing and 40 feet of tunnel was excavated.

Geologic mapping of the Starter Tunnel, Test Alcove #1, and drainage channel was completed. Geologists provided geotechnical data and analysis to the tunnel designs to assess

the adequacy of ground support and other safety factors in the Starter Tunnel and Alcove. Preparations were begun for the upcoming mapping behind the tunnel boring machine to ensure rapid startup for new mapping crews and integration of the activities of underground mapping, including site characterization and design verification.

Exploratory Studies Facility design activities supporting the tunnel boring effort this period included ongoing modifications for Design Package 1 (North Portal Site Preparation and Surface Facilities), near completion of Design Package 2 for the North Ramp Excavation, Surface to Topopah Spring Level, and the beginning of Design Package 8 for the Topopah Spring level main drift. The Integrated Data and Control System Design Package completed a 50% Design Review during the period. This system combines the functions of an integrated data system and a facilities monitoring control system into a single system to reduce cost and optimize system use. The integrated data system, which is to be developed in phases, will allow control, monitoring, and data collection to record and archive construction and site characterization data for the Principal Investigators as well as data required by Department of Energy Order 6430.1A (General Design Criteria).

The new focused Advanced Conceptual Design for the repository was fully implemented during this period. This new design process, which is based on selecting a single primary design concept that meets the repository and waste package requirements, will help expedite the design process. This design has the fundamental objectives of (1) developing a project scope that satisfies program needs, (2) ensuring project feasibility and attainable technical performance levels, (3) identifying and quantifying project risks, and (4) developing a reliable cost estimate and a realistic performance schedule.

The focused Advanced Conceptual Design for the repository will expedite the design process.

Design activities to support the focused Advanced Conceptual Design included identifying potential changes in the repository layout to enhance constructability and better utilize the emplacement block, identifying data needed from site characterization to support design, further defining zones acceptable for waste emplacement, initially defining an emplacement drift spacing strategy, and measuring radon concentrations in the repository drift. The Project also determined that the center-in-drift emplacement mode is the most cost-effective under current assumptions. An interim report on thermal loading for the underground facility was completed, and the Controlled Design Assumptions Document was issued. The Initial Advanced Conceptual Design Summary Report, and a draft Concept of Operations for the Mined Geological Disposal System were also completed. Laboratory tests were begun on candidate sealing materials and a sealing and backfilling strategy was developed for openings.

Waste package is nearing the end of Advanced Conceptual Design. The design concepts incorporate the multi-purpose canister.

The waste package design is nearing the end of Advanced Conceptual Design. Three concepts for the disposal container have been developed to cover the containers needed for multi-purpose canisters, uncanistered fuel, and defense high-level waste. All three incorporate the multibarrier disposal container configuration. The multi-purpose canister is being used as the primary option for Advanced Conceptual Design, although a final decision to fabricate and deploy the multi-purpose canister is contingent on results of the Environmental Impact Statement process. The decision to move forward with the multi-purpose canister concept was based on the premise that it could handle the vast majority of commercial spent nuclear fuel at a reasonable cost, while ensuring the safety of the public and protecting the environment. The conceptual design of the multi-purpose canister is based on adapting existing technology.

In other waste package work, candidate materials have been identified for the fabrication of different components of the multibarrier waste packages and different thermal loadings. In addition, efforts to determine the design basis fuel considered two waste receipt scenarios: oldest fuel first and youngest fuel first. Studies continued to characterize the waste package environment and waste forms and to evaluate the containment and control of release from various waste package designs and components.

Epilogue

The earlier portion of this Executive Summary provided a summary of major decisions, activities, accomplishments, and issues of interest during the reporting period; this section provides a high level summary of key events that occurred after the close of the reporting period on September 30, 1994, and prior to printing this report.

The Department received a letter from the Commission on October 13, 1994, expressing concerns with the Quality Assurance Program. The Commission identified issues related to the Civilian Radioactive Waste Management System Management and Operating Contractor Quality Assurance Program and the Department role in the oversight of that Program. The concerns resulted from deficiencies identified by the Department during Quality Assurance audits and surveillances of the Management and Operating Contractor's design process and on independent design reviews of Design Packages 2A and 2B performed by the Department and its contractors. A response was prepared to the Commission outlining actions to be taken by the Management and Operating Contractor and the Department to ensure effective implementation and oversight of the Quality Assurance Program.

On December 19, 1994, Dr. Dreyfus briefed the Nuclear Regulatory Commission. Provided at that briefing were draft copies of the Civilian Radioactive Waste Management Program Plan. That draft of the Program Plan incorporated the Five-Year Plan as Volume II. Also provided at that briefing were copies of the Yucca Mountain Site Characterization

Project's fiscal year 1995 Technical Implementation Plans, which contain a complete work scope and rationale for fiscal year 1995 activities. These planning documents implement the new Office of Civilian Radioactive Waste Management System program approach. The Five-Year Plan itself will not be carried forward except as a component of the Program Plan, which will form the basis for the new baseline to be completed over the next several months.

CHAPTER 1 - INTRODUCTION

This chapter provides the statutory basis for the Site Characterization Progress Report, followed by background information that leads into a description of the new Program Approach.

1.1 PURPOSE AND SCOPE

In accordance with Section 113(b)(3) of the Nuclear Waste Policy Act of 1982 (NWPA, 1983), as amended (NWPAA, 1987) and 10 CFR 60.18(g), the U.S. Department of Energy (DOE) has prepared this report on the progress of site characterization activities at Yucca Mountain, Nevada, for the period April 1, 1994, through September 30, 1994. This report is the eleventh in a series issued at intervals of approximately six months during site characterization activities undertaken to evaluate Yucca Mountain as a possible geologic repository for the permanent isolation of spent nuclear fuel and high-level radioactive waste.

Section 113(b)(3) of the Nuclear Waste Policy Act, as amended, states:

> "During the conduct of site characterization activities at the Yucca Mountain site, the Secretary [of Energy] shall report not less than once every 6 months to the Commission and to the Governor and legislature of the State of Nevada, on the nature and extent of such activities and the information developed from such activities."

In conjunction with these requirements, 10 CFR 60.18(g) states:

> "During the conduct of site characterization activities, DOE shall report not less than once every six months to the Commission on the nature and extent of such activities and the information that has been developed, and on the progress of waste form and waste package research and development. The semiannual reports shall include the results of site characterization studies, the identification of new issues, plans for additional studies to resolve new issues, elimination of planned studies no longer necessary, identification of decision points reached and modifications to schedules where appropriate. DOE shall also report its progress in developing the design of a geologic repository operations area appropriate for the area being characterized, noting when key design parameters or features which depend upon the results of site characterization will be established. Other topics related to site characterization shall also be covered if requested by the Director."

This Site Characterization Progress Report presents summaries of the status of site characterization activities and cites technical reports and research products that provide more detailed information on such activities. The report highlights work started, work in progress, and work completed during the reporting period. In addition, this report documents and discusses changes to the Office of Civilian Radioactive Waste Management (OCRWM) Site Characterization Program resulting from ongoing collection and evaluation of site information,

systems analyses, development of repository and waste package designs, and results of performance assessment activities.

The references cited in the text are available for inspection at DOE public reading rooms in Nevada and Washington, D.C., the open literature, or through proceedings volumes for symposia and technical conferences. Copies of government publications may also be obtained through the DOE Office of Scientific and Technical Information at Oak Ridge, Tennessee, or the National Technical Information Service in Springfield, Virginia.

1.2 BACKGROUND INFORMATION

Yucca Mountain has not been selected as a site for a repository. Rather, it has been designated by the U.S. Congress as the only candidate repository site to be characterized to determine whether or not it is suitable for development as a repository. In accordance with Section 113 of the Nuclear Waste Policy Act, as amended, OCRWM is conducting a program of detailed site-specific investigations and evaluations to assess the suitability of Yucca Mountain. The plans, activities, and results of the site characterization program are reviewed by the U.S. Nuclear Regulatory Commission (NRC), the Nuclear Waste Technical Review Board (NWTRB), State of Nevada, and other external organizations and interested parties.

If Yucca Mountain is found to be suitable for development as a repository and is recommended for such development by the President and approved by Congress, if necessary, OCRWM will be required to demonstrate to NRC that the potential repository system will meet applicable regulations. If, during the course of scientific investigations, information supports a finding that the Yucca Mountain site is unsuitable for development as a repository, OCRWM will terminate all characterization activities at the site. Should that occur, OCRWM will, in accordance with provisions of the Nuclear Waste Policy Act, as amended, notify Congress and the Governor and legislature of the State of Nevada of its action and the reason for such action.

Studies have been conducted at Yucca Mountain since the late 1970s to support programmatic site screening and provide information for the Environmental Assessment (DOE, 1986). Surface-based studies at Yucca Mountain have been in progress since May 1986. Initially, these studies consisted of non-surface-disturbing testing in existing exploratory boreholes and wells; analyses of, and experiments with rock and water samples; geophysical surveys; meteorological, hydrologic, and seismic monitoring; geologic mapping, and sampling of surficial materials. New surface-disturbing work began in July 1991 when the State of Nevada granted necessary permits, with expanded surface-based activities started in November 1992, to support construction of the Exploratory Studies Facility North Portal.

The plans for site characterization are described in the Site Characterization Plan (DOE, 1988), with additional detail provided in study plans for the various site characterization studies and their component activities. The Site Characterization Plan contains extensive testing, design, and performance assessment programs that would produce a comprehensive understanding of Yucca Mountain. The Site Characterization Plan was submitted to NRC in

December 1988, and the Site Characterization Analysis (NRC, 1989) was issued in July 1989. Responses to comments from NRC, State of Nevada, affected units of local government, other interested parties and agencies, and the public were addressed by OCRWM and the Yucca Mountain Site Characterization Office (YMSCO). Changes to the statutory Site Characterization Plan are documented in technical baseline documents, primarily the Site Characterization Program Baseline (DOE, 1994a). Approved revisions to baseline documents are discussed in each Site Characterization Progress Report. The baseline control process is discussed in Section 2.1, which reports the status as of the end of this reporting period.

1.3 PROGRAM APPROACH

During the previous reporting period, as noted in Progress Report #10, DOE conducted preliminary evaluations of options for restructuring the Repository Program. This led, over the course of the current reporting period, to a change in the approach to site characterization. The new approach, hereinafter referred to as the Program Approach, is discussed in this section. Progress in Program Approach development and implementation is reported in Chapter 2.

Under the Nuclear Waste Policy Act, as amended, DOE is responsible for siting, constructing, and operating a geologic repository for the disposal of high-level nuclear waste. The DOE must complete four major actions before a repository can be sited and constructed: (1) determine if the site is suitable under 10 CFR Part 960; (2) prepare an Environmental Impact Statement, and related documentation, specified in Section 114(f) of the Nuclear Waste Policy Act, as amended, in accordance with the National Environmental Policy Act, as amended (NEPA, 1969), and 10 CFR Part 1021; (3) prepare a Site Recommendation Report and submit an Environmental Impact Statement to the President; and (4) prepare a License Application for submittal to NRC for a construction authorization under 10 CFR Part 60, if the President recommends and, if necessary, Congress approves the site.

In developing the Program Approach, DOE re-evaluated its approach to achieving the objectives of the Nuclear Waste Policy Act, as amended, to ensure that (1) efficient, measurable progress is made toward determining the suitability of the Yucca Mountain site for a permanent repository and, if the site is suitable, the Program is able to proceed with the Environmental Impact Statement, site recommendation, and licensing and construction of a repository; and (2) the technical approach and schedule are realistic and consistent with the increased funding levels proposed by the administration in the budget request for fiscal year (FY) 1995, and with expectations of stakeholders, including Congress.

The Program Approach is an attempt to bring the Program back to the original intent of the legislative and regulatory framework. The Nuclear Waste Policy Act, as amended, and 10 CFR Part 60, established the framework for conducting a program of site characterization that would provide sufficient information for decision-making, realizing that some residual uncertainties would exist. The DOE decision to proceed with the Program Approach was, in part, a recognition that expectations have built up over the years that cannot be satisfied with the budget that is likely to be available and within an acceptable timeframe. The 1988 Site

Characterization Plan presented a comprehensive testing, design, and performance assessment program, and both external and internal pressures since 1988 have tended to broaden, rather than focus the Program. The Program Approach brings focus to the plans for site characterization and design by establishing a sequence of suitability and licensing decisions that will be made on the basis of a knowledge base that is increasing with time. The sequence of testing and design activities is being revised to provide timely information to support these decisions. Many aspects of the philosophy embodied in the Program Approach are consistent with recommendations of the National Academy of Sciences (NAS), contained in "Rethinking High-Level Radioactive Waste Disposal, a Position Statement of the Board on Radioactive Waste" (NAS, 1990). That report stressed that it is not practical to assume all information would be available prior to constructing the repository.

The Program Approach initially focuses the Program on an evaluation of the technical suitability of Yucca Mountain by 1998, followed by an evaluation of overall suitability in 2000. The evaluation process centers on a step-wise demonstration of compliance with each 10 CFR Part 960 siting guideline, or groups of guidelines. If Yucca Mountain is found to be suitable, the Secretary's decision to recommend the site to the President for development as a repository will be supported by an Environmental Impact Statement, the Site Recommendation Report, and preliminary comments by the Commission about the sufficiency of site characterization and waste form information for inclusion in a License Application. If the President recommends the site and Congress approves it, if necessary, then DOE will submit a License Application for a construction authorization to the Commission in 2001. This License Application is intended to provide the basis for the Commission to develop high confidence about the safety of repository operations and the ability of the waste packages to contain the waste for more than 1000 years. Realistically conservative bounding arguments will be presented to demonstrate compliance with the release limits for the engineered system and for total system performance. Through additional testing during performance confirmation, DOE expects to gain information that will increase confidence in overall system performance, which will serve as a basis for an update to the License Application in about 2008. This update will contain information to support a license to proceed with receipt and emplacement of waste in the repository. Performance confirmation testing will continue during repository operations, and it is likely that initial licensing conditions could be modified in updates to the License Application.

With the initial focus on suitability, priority will be given to site characterization and engineering activities most important for evaluation of the suitability of the Yucca Mountain site. Activities needed to support development of the Environmental Impact Statement and the License Application will be carried on concurrently to the extent that funding allows. Information developed for use in suitability evaluations will also be used for environmental and licensing purposes, and additional information will be developed as required to support preparation of the Environmental Impact Statement and License Application.

During this and the previous reporting period, existing plans for site characterization, performance assessment, and repository and waste package design activities were carefully reviewed by a multidisciplinary team with the goal of laying out a sequence of work activities that supports the decisions required at each major milestone defined in the Program

Approach. This review will continue and is likely to result in additional revisions to plans and schedules for site testing, performance assessment, and design activities. To date, surface and underground testing has been sequenced to provide the highest confidence about site suitability and repository performance that is possible, within funding limitations and schedule constraints, to support DOE and NRC decisions. The level of design detail that should be available to support each major decision point is being analyzed and design schedules are being revised to support milestones defined by the Program Approach.

Additional information about how the Program Approach is being implemented through the major elements of the Repository Program (site suitability evaluation, the National Environmental Policy Act process, and the repository licensing process) is provided in the following sections.

1.3.1 Repository Site Suitability Evaluation and Site Recommendation

The Program Approach provides a management tool to focus site characterization and engineering activities on that information deemed necessary and sufficient to support a technical site suitability evaluation of Yucca Mountain in 1998. The site studies and engineering activities being conducted are a subset of those described in the 1988 Site Characterization Plan, with some modifications and additions that have been reported in previous Semiannual Progress Reports. The site suitability evaluation centers on a step-by-step demonstration of compliance with each 10 CFR Part 960 siting guideline, or groups of guidelines. This approach facilitates strategic planning at lower functional levels. Making conclusions on the individual higher-level findings, and an evaluation of technical site suitability, provides a logical means to reach convergence on the scientific program, to establish priorities and allocate appropriate resources, and demonstrate accountability and progress to external stakeholders.

Key uncertainties that need to be addressed to evaluate suitability relate back to the underlying strategy for proposing the Yucca Mountain site as a potential repository. If it can be shown that low liquid saturations and low aqueous flux limits corrosion of the waste package and releases of radionuclides, this will be an important component of the Total System Performance Assessment that will support the compliance argument for the postclosure guidelines. An important corollary to this argument is that impacts of repository thermal loading on moisture contacting the waste package and resultant corrosion rates will have to be understood or bridged with conservative assumptions. This strategy leads to a focus on understanding hydrologic flux and flow mechanisms in the unsaturated zone.

The pre-1998 Surface-Based Site Testing Program will use existing boreholes, together with a limited number of strategically placed new boreholes, to obtain adequate pneumatic data prior to excavation of the Exploratory Studies Facility beyond the point where undisturbed background data could not be obtained. This will be helpful for predicting movement of moisture through Yucca Mountain under both existing conditions and conditions that would exist after repository development, if a repository is developed at Yucca Mountain. The geophysics program will be given additional priority to improve predictive capabilities,

particularly for subsurface areas where excavations are not planned prior to 1998. This will provide important information about the presence of fracture zones that could serve as pathways for rapid flow. Boreholes to investigate the steep hydraulic gradient to the northwest of the site are also a high priority, due to the need to incorporate this feature into hydrologic models of the site. These studies will reduce uncertainty in calculations of ground-water travel time that provide a basis for evaluating the 10 CFR Part 960 Disqualifying Condition for Geohydrology, as well as improve confidence in predictions of total system performance.

The sequence of excavation of the Exploratory Studies Facility, as well as the tests that will be completed prior to 1998, were carefully planned to provide the highest possible confidence for the Program Approach milestones. The excavation sequence was streamlined by deferring some testing alcoves to allow access to the Ghost Dance fault zone at the earliest possible opportunity. In situ observation of this feature is important to establish whether it could serve as a preferential flow path from the repository to the water table, again contributing to the understanding that serves as a basis for evaluating the Geohydrology Disqualifying Condition. Testing alcoves were prioritized to allow observation of key contacts and fault zones as early as possible, and tests in the alcoves are focused on geology and hydrology for the pre-1998 period.

The process for evaluating suitability calls for the step-wise evaluations of individual guideline conditions, or groups of guideline conditions, of 10 CFR Part 960. Evaluations will be conducted as site characterization data and analyses become available and will be based upon an assessment of the site and related design concepts to determine whether guideline conditions are satisfied. The environmental aspects of the evaluation will use data and analyses developed to implement the National Environmental Policy Act process. For each guideline or group of guidelines, OCRWM would first develop a technical basis report and then, using the technical basis report, develop a guideline compliance assessment.

The process features three types of OCRWM evaluations, the first being evaluations leading to higher-level findings on individual guideline conditions. An evaluation of technical site suitability will follow, and finally an evaluation of overall site suitability will be made. These OCRWM evaluations will be the basis for the Director's recommendation to the Secretary of Energy to submit the Site Recommendation Report to the President in 2000. Preliminary comments from NRC on the sufficiency of the DOE site characterization analysis and waste form proposal for inclusion in a License Application must also accompany the Secretary's recommendation to the President. The Site Recommendation Report submittal is a final agency action and is the DOE's formal decision regarding the suitability of the site.

1.3.2 National Environmental Policy Act Process for Repository Development

According to the Nuclear Waste Policy Act, as amended, any Site Recommendation Report must be accompanied by an Environmental Impact Statement. The Program Approach to the development of environmental activities includes initiation of the National Environmental Policy Act process with the Notice of Intent and opening of the public scoping

process in 1995 to establish the scope of the issues to be addressed in the Environmental Impact Statement. The schedule calls for the Draft Environmental Impact Statement in 1998 and the Final Environmental Impact Statement in 2000.

The evaluations conducted to satisfy requirements under the National Environmental Policy Act and the DOE implementing regulation, 10 CFR Part 1021, would be based on the repository Advanced Conceptual Design and would provide input to the site suitability evaluations for evaluation of environmental, socioeconomic, and transportation guidelines in 10 CFR Part 60. The Final Environmental Impact Statement will provide input to the DOE evaluation of overall site suitability and will accompany the Site Recommendation Report to the President, as required by Section 114(f) of the Nuclear Waste Policy Act, as amended.

1.3.3 Repository Licensing Process

If the Yucca Mountain site is found to be suitable, and a site recommendation is made and approved by the President and Congress, if necessary, DOE will submit a License Application to NRC. Repository licensing under NRC regulations will be an incremental process, beginning with submittal of the initial License Application for construction authorization, an updated application for a license to receive and possess spent nuclear fuel and high-level waste, and a final application for a license amendment to close the repository. Additional applications for license amendments to permit changes in design or operating conditions may be submitted as needed.

As was discussed above for the suitability milestones, the appropriate sequence of site testing and design activities to provide the highest possible confidence for licensing decisions is being carefully evaluated. The focus of site testing in the 1998-2001 timeframe will be to develop the engineering parameters needed to prepare the License Application for construction authorization. Similarly, for the post-2001 timeframe, those tests designed to improve confidence about long-term performance will be a high priority as part of the performance confirmation program required under 10 CFR 60, Subpart F. The long-duration in situ tests that measure moisture redistribution and changes in rock properties in response to thermal loading will be key information sources during this timeframe. With regard to the engineered system, confirming the behavior of engineered materials within the range of expected repository conditions will be given high priority.

The Safety Analysis Report supporting the License Application for construction authorization will be based on a Title I (preliminary) design for the repository and a Title II (final pre-fabrication) design for the waste package. The focus will be on ensuring the safety of repository operations and providing high confidence in waste package containment.

Predictions about the long-term ability of the repository's engineered and natural barriers to contain and isolate spent nuclear fuel and high-level waste, based upon the available data and supported by bounding analyses and models, will be included in the initial License Application. These predictions, together with the other evidence to be presented, should be sufficient to allow NRC to determine whether a finding of "reasonable assurance"

can be made and to support a decision as to whether or not their objectives for the long-term performance of the repository system will be met. This determination will be made consistent with NRC requirements and expectations provided in 10 CFR 60.24(a) ("The application . . . shall be as complete as possible in the light of information that is reasonably available at the time of docketing.") and in 10 CFR 60.101(b) (". . . the demonstration of compliance may take uncertainties and gaps in knowledge into account . . . .").

After construction is substantially complete and NRC has issued the license to receive and possess spent nuclear fuel and high-level waste, the scientific work will be focused to obtain data on changes to the site caused by repository construction and by the effects of waste emplacement. The objective will be to confirm, in accordance with 10 CFR 60.140(a), the basis for earlier predictions about containment and isolation and to test the models that will be relied upon for confirming the long-term predictions required to support a decision by NRC to permit closure of the repository.

Under the Program Approach, the repository will be designed to permit waste retrieval for up to 100 years from the date of first emplacement to ensure the opportunity to obtain test results and monitor repository behavior over an extended performance confirmation period, should that be necessary. The License Application for an amendment to close the repository will not be submitted until sufficient confirmatory test information is available to provide adequate confidence to support a decision to close the repository.

The schedule calls for the License Application for construction authorization to be submitted by DOE to NRC in 2001, the updated application for a license to receive and possess spent nuclear fuel and high-level waste in 2008, and the application for an amendment to permit closure in, or before, 2110.

CHAPTER 2 - PROGRAMMATIC ACTIVITIES

This chapter reports progress in Program Approach development, which continued throughout the reporting period in preparation for its implementation in FY 1995. Future Progress Reports, beginning with Progress Report #12, will report the results of Program Approach implementation, including any changes in the official baseline and site characterization programs.

Programmatic activities focus, evaluate, plan, control, and ensure the quality of site characterization, design, and performance assessment activities. Long-range and annual Technical Implementation Plans implement Project priorities, map proposed budgets to those priorities, and produce detailed work scope statements including comprehensive completion criteria. Regulatory activities, including the development of product outlines and interactions with oversight organizations, identify and evaluate the information needed to determine the suitability of the site, develop the Environmental Impact Statement, and produce a License Application. Requirements, constraints, and design configurations are baselined and changes are reported in the Site Characterization Progress Reports. Finally, the public outreach program communicates issues to the public to foster a climate of understanding, which is consistent with provisions in the Nuclear Waste Policy Act of 1982, as amended, that provide for public involvement in the site characterization process.

2.1 PROJECT PLANNING AND BASELINE CONTROL

Detailed project planning to prepare for Program Approach implementation progressed throughout the reporting period. The Project continued to develop a new Five-Year Plan (DOE, in prep.[a]) consistent with the increased congressional allocation, to implement the objectives of the Program Approach. Development of the Technical Implementation Plans for FY 1995 (CRWMS M&O, in prep.) was initiated to produce detailed work scope statements including comprehensive completion criteria. Any changes in the cost, schedule, and technical baselines that result from Program Approach implementation will be reflected in the OCRWM Document Hierarchy and reported in future Site Characterization Progress Reports. Progress in these planning and baseline control activities to prepare for Program Approach implementation is reported in this section.

2.1.1 Five-Year Plan

The DOE developed a draft Five-Year Plan for the Yucca Mountain Site Characterization Project (YMP). This plan will be the basis for input to the OCRWM Program Plan that is also under development. The Five-Year Plan describes the goals, activities, and schedule milestones for the major products of the Project for FYs 1996-2000. The plan implements the site suitability, National Environmental Policy Act, and repository licensing strategies established in the Program Approach discussed in Section 1.3.1.

Key features of the Five-Year Plan are:

- Description of the activities necessary to implement the Program Approach
- Clear definition of expected progress with interim milestones and products
- Clarification of the relationships among activities, products, and budgets.

The proposed activities for the refocused Project are presented in terms of the following four major areas and the products required to meet the near-term goals of the Program Approach:

1. Site suitability includes the activities required to support the Technical Site Suitability Evaluation scheduled for 1998, which assesses those suitability conditions that were addressed in the Site Characterization Plan (DOE, 1988) and that depend on information from site characterization. Subsequent to the 1998 evaluation, DOE will complete an evaluation of the remaining guidelines addressing environmental quality, transportation, and socioeconomic impacts and make an evaluation regarding the overall suitability of the site in 2000. A final DOE decision to recommend the site for development as a repository is expected in 2000 and would be based on the overall evaluation of site suitability, completion of the Environmental Impact Statement, and input received from stakeholders and oversight groups.

2. The process under the National Environmental Policy Act includes the activities required to collect, interpret, and analyze data required for the preparation of the draft and final Environmental Impact Statement, in FY 1998 and FY 2000 respectively, and the review of these documents.

3. Repository licensing includes the activities required to ensure that information will be available to develop a License Application for submission to NRC in FY 2001, if the site is suitable and the site recommendation is approved by the President and Congress, if necessary.

4. Management and compliance includes normal management activities required for direction and control of the Project and special allocation required to support external agencies and the public in their review and interactions with the Project.

Accomplishment of the project activities in the Five-Year Plan will produce the following results:

- By the end of FY 1998:

  - The DOE will use results from the phased testing program to evaluate the technical suitability of the site at Yucca Mountain for development as a geologic repository—three years earlier than planned in the schedule established by the Secretary of Energy in 1989.

- The DOE will develop a draft Environmental Impact Statement for public comment.

- By the end of FY 2000:

  - The DOE will evaluate the overall suitability of the site for development as a geologic repository.

  - If Yucca Mountain is suitable, the DOE will deliver a final Environmental Impact Statement and a Site Recommendation Report to the President—meeting milestones a year ahead of dates originally established in 1989.

- By the end of FY 2001:

  - If the President recommends the site and Congress approves it, if necessary, DOE will submit a License Application for construction of a repository to NRC and be prepared to support the NRC legal obligation to decide on the repository construction authorization within three years of the date of the application. The License Application will be developed from information that is fed forward from the site suitability evaluations and additional information, as appropriate.

Forecast: The scope and schedule information in the Five-Year Plan will be finalized during the next reporting period and the information will be used in Volume II of the OCRWM Program Plan (DOE, in prep.[b]).

2.1.2 Technical Implementation Plans

During the last half of FY 1994, the Project focused on completion of FY 1995 Technical Implementation Plans for the majority of the Project Work Breakdown Structure elements. Activities proposed in these plans implement the OCRWM Program Approach as presented to NRC in its July 26, 1994, management meeting with DOE and in the September 21, 1994, ACNW meeting. Also, the final FY 1994 Project Technical Implementation Plan (DOE, 1994b) was completed, thus providing an integrated presentation of the year's activities and how they supported the Project goals.

The FY 1995 Technical Implementation Plans include clear implementation of Project priorities, mapping of proposed budget to those priorities, detailed work scope statements, and proposed milestones and deliverables including comprehensive completion criteria. Logic for planned work was checked against the OCRWM Program Approach master schedule and was evaluated for appropriate predecessor and successor activities.

The FY 1995 Technical Implementation Plans support the draft Project Five-Year Plan recently generated for FYs 1996-2000 to implement the OCRWM Program Approach. The draft Five-Year Plan defines activities, budgets and milestone schedules needed for the Project's three major products: Site Recommendation Report, Environmental Impact

Statement, and License Application for repository construction, and a new interim suitability milestone in 1998. The draft Five-Year Plan is consistent with the Administration Funding Proposal and Congressional budget profiles and demonstrates meeting OCRWM Program Approach schedules for the Project deliverables.

Forecast: The final FY 1995 Technical Implementation Plans are expected to be issued after budgets are finalized, currently scheduled for December 1994. The draft FY 1996 Technical Implementation Plans are expected to be issued in March 1995, reflecting the results of the Technical Project Review scheduled for the previous month.

2.1.3 Schedule

The schedule baseline for the Project presented in Progress Report #10 (DOE, 1994c) did not officially change during this reporting period. Rather than reproduce the schedule baseline, this section presents the summary schedule that is consistent with the Program Approach. As the Program Approach is further defined, some of these milestones may need to be revised, and will be reported in subsequent Progress Reports. During FY 1995, the Project will be conducting those activities needed to baseline the Project schedule.

Table 2-1 presents the summary milestones for the Project. Figure 2-1 shows the relationship of the summary milestones to other key Project activities.

2.1.4 Document Hierarchy and Program Baseline

Progress Report #10 discussed the development of Civilian Radioactive Waste Management System facilities using a systems engineering approach and the fact that the various technical requirements and regulatory constraints are allocated to the different system elements. All requirements and constraints are captured in the OCRWM Document Hierarchy shown in Figure 2-2, and all technical requirements documents identified in the Regulatory Controls side of the hierarchy are baselined.

2.1.4.1 Regulatory Controls

The Mined Geologic Disposal System requirements and constraints are contained in documents that are derived from the Mined Geologic Disposal System Requirements Document (DOE, 1994d). These lower-tier documents identify the requirements (including interface requirements) and constraints for each Mined Geologic Disposal System segment.

Table 2-1. Preliminary Summary Schedule

Milestone	Date
Site Suitability	
HLFs on Surface Processes	9/95
HLFs on Preclosure Rock Characteristics	9/96
HLFs on Seismic/Tectonics/Volcanism	1/97
HLFs on Geochemistry/Postclosure Rock Characteristics	2/97
HLFs on Reasonably Available Technology	2/97
HLFs on Preclosure Radiological Safety	7/97
HLFs on Geohydrology/Transport	12/97
HLFs on Total System Performance/Remaining Postclosure QCs	9/98
Technical Site Suitability	9/98
Site Recommendation Report	9/00
National Environmental Policy Act Process	
EIS Notice of Intent	3/95
EIS Implementation Plan	12/95
Draft EIS	9/98
Final EIS	8/00
Record of Decision	9/00
Licensing	
LA Annotated Outline, Rev. 0	3/95
LA Annotated Outline, Rev. 1	1/96
LA Annotated Outline, Rev. 2	1/97
LA Annotated Outline, Rev. 3	1/98
LA Annotated Outline, Rev. 4	1/99
LA Annotated Outline, Rev. 5	1/00
License Application	6/01
Exploratory Studies Facility Construction/Testing	
Complete North Ramp	3/96
Complete Excavation of 1st Ghost Dance Fault Drift	9/96
Complete Excavation of 2nd Ghost Dance Fault Drift	12/96
Complete Excavation for Short-Term Heater Tests	11/96
Complete South Ramp/Daylight	6/97
Complete North Ramp Extension	9/98
Waste Package/Repository Design	
Complete Repository/Waste Package Advanced Conceptual Design	3/97
Complete Repository/Waste Package License Application Design	9/00

Note: EIS = Environmental Impact Statement; HLFs = Higher-Level Findings; LA = License Application; QC = Qualifying Condition

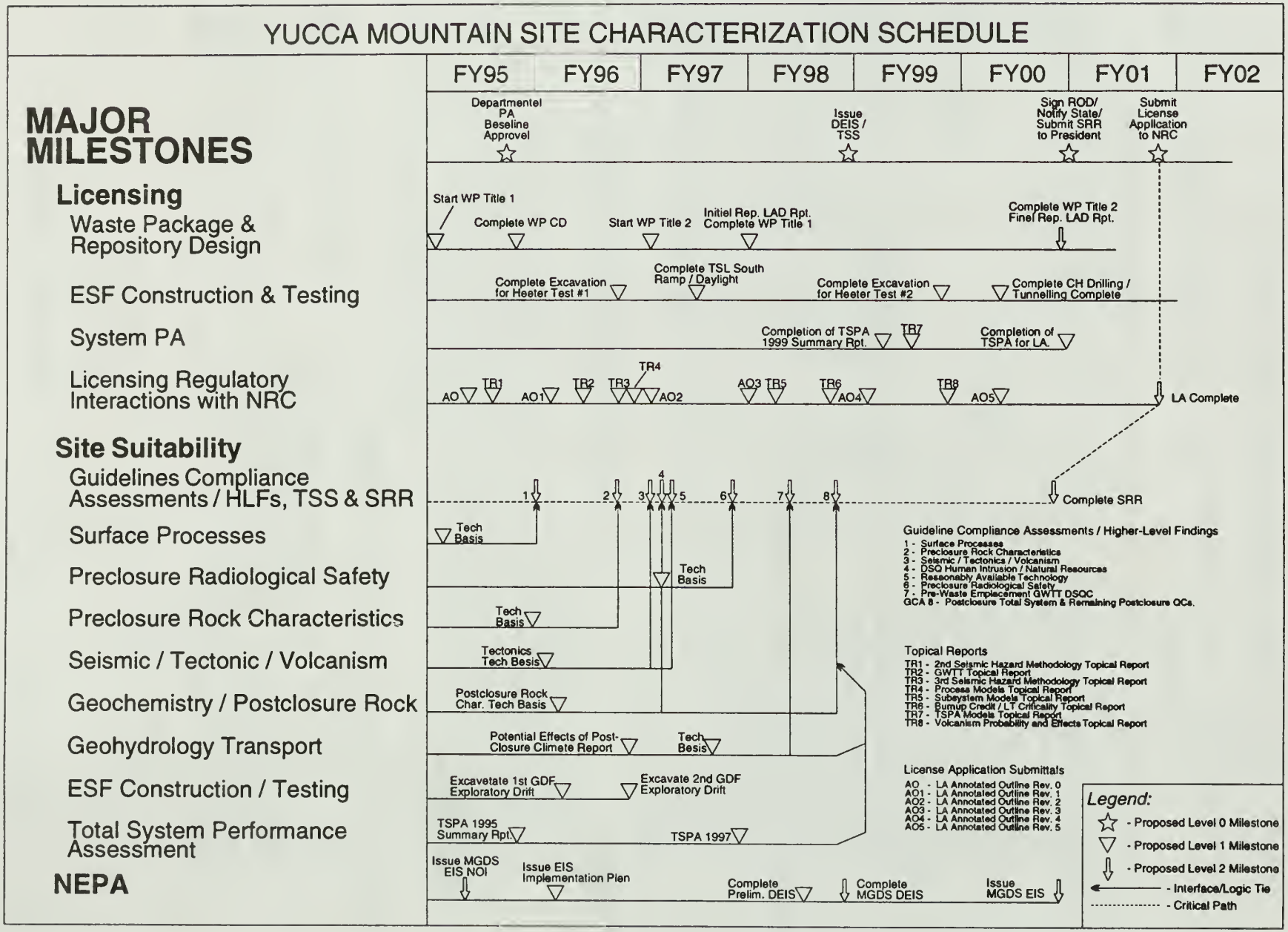


Figure 2-1. Yucca Mountain Site Characterization Schedule

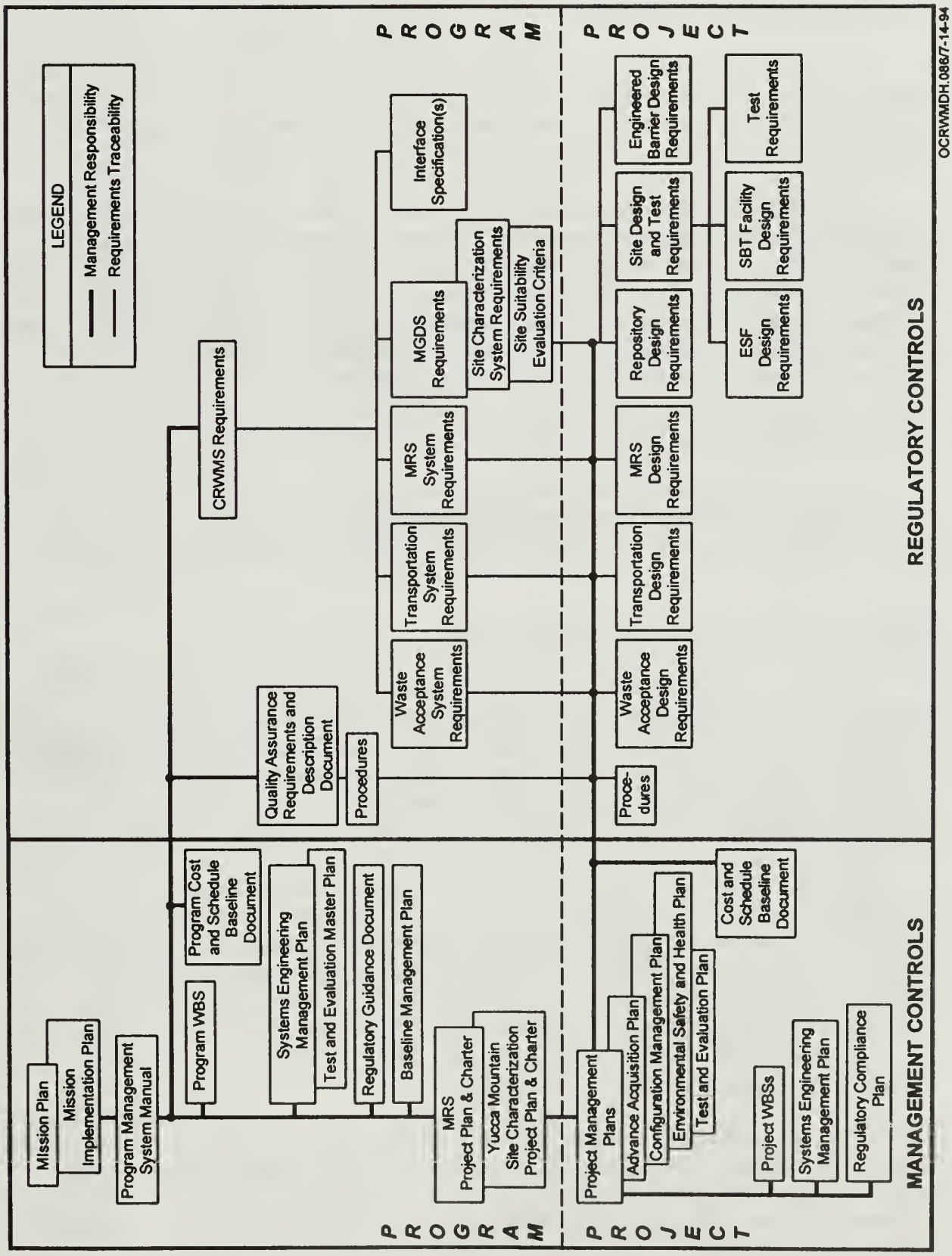


Figure 2-2. OCRWM Document Hierarchy

Site Design and Test Requirements

The Site Design and Test Requirements Document (DOE, 1994e) was revised during this reporting period to incorporate changes to the parent documents. The revision focused on the development of requirements backup sheets, the review of source inputs to verify their qualification, and the closure of requirements that could not be verified.

The objective of the requirements backup sheet is to provide a location to document the rationale for any translation or change to a requirement as it was stated in the parent document. For example, if the Mined Geologic Disposal System Requirements Document has a requirement that states "the Mined Geologic Disposal System design shall address availability as a factor in determining the operational capacity of its subsystem" and the Site Design and Test Requirements document states "Exploratory Studies Facility availability for critical support systems is 97 percent," then the rationale for this derivation is provided on the requirements backup sheet for this requirement. The review of source inputs to determine if any unqualified inputs were used was performed and resulted in no impact to the document.

The resolution of items to be determined or verified focused only on those needed to support Exploratory Studies Facility Design Requirements (DOE, 1994f) changes, which in turn were needed to support the Exploratory Studies Facility Design Packages produced during FY 1994.

Exploratory Studies Facility Design Requirements

The Exploratory Studies Facility Design Requirements was the subject of two interim changes and a major revision during this reporting period, which primarily focused on closure of requirements that were either not verified or not determined. These interim changes were required to support Exploratory Studies Facility Design Packages which were to be produced in advance of the scheduled Exploratory Studies Facility Design Requirements revision. The interim changes also addressed other minor changes needed to support the design activities.

The revision focused on the development of requirements backup sheets, the review of source inputs to verify their qualification and the closure of requirements that were either not verified or not determined. The revision also addressed any remaining requirements that were either not verified or not determined as needed to support Exploratory Studies Facility Design Packages. The primary objective of the revision was to develop requirements backup sheets and verify the qualification of source inputs.

Surface-Based Testing Facilities Requirements

The Surface-Based Testing Facilities Requirements (DOE, 1994g) was revised and the objectives for this revision were basically the same as those identified for the Exploratory Studies Facility Design Requirements, except for the need to resolve unverified and undetermined items to support Design Packages. No new Surface-Based Testing Facilities designs were developed.

Forecast: A revision of each of the lower-tier documents is planned for FY 1995 to allocate requirements to configuration items.

2.1.4.2 Management Controls

The YMP management requirements and constraints are contained in documents identified as Management Controls on the lower left side of the OCRWM Document Hierarchy (Figure 2-2). These documents identify the approach for management of the Project activities in accordance with applicable management requirements.

Project Management Plan

The Project Management Plan (DOE, 1990a) has not undergone any changes during this reporting period.

Advance Acquisition Plan

The Advance Acquisition or Assistance Plan (DOE, 1992a) has not undergone any changes during this reporting period.

Configuration Management Plan

The Configuration Management Plan (DOE, 1992b) has undergone two interim changes during this reporting period. Interim Change Notice 1 added the Change Control Board thresholds in accordance with the Baseline Management Plan for Levels 2 and 3, deleted the Raytheon Services Nevada Configuration Items and Configuration Item Identifiers, and inserted the new Work Breakdown Structure/Configuration Items and Configuration Item Identifiers for both Surface-Based Testing and Exploratory Studies Facility areas, and added additional notes clarifying the procedures to use for identification of Configuration Items. Interim Change Notice 2 redefined the Configuration Item numbering scheme to align with the Project Work Breakdown Structure.

Environmental, Safety and Health Protection Implementation Plan

In lieu of the Environmental, Safety, and Health Protection Implementation Plan indicated on the Document Hierarchy, the Project has issued a Safety and Health Plan (DOE, 1994h) and is preparing an Environmental Management Plan (DOE, in prep.[c]).

Test and Evaluation Plan

The Test and Evaluation Plan (DOE, 1993a) has not undergone any changes during this reporting period.

Project Work Breakdown Structure

The Project Work Breakdown Structure (DOE, 1994i) has undergone major changes to incorporate Project Change Control Board actions during the reporting period. Twenty-eight Cost and Schedule Change Requests that modified the Project Work Breakdown Structure were approved by the Project Change Control Board. Eighteen of the approved changes were to be effective and implemented on October 1, 1994. These changes contained major modifications to the subelements of the following third-level Work Breakdown Structure elements: 1.2.1, Systems Engineering; 1.2.2, Waste Package; 1.2.4, Repository; 1.2.6, Exploratory Studies Facility; 1.2.9, Project Management; 1.2.12, Information Management; and 1.2.15, Support Services. Additional Work Breakdown Structure changes in process will delete Technical and Management Support Services as a participant from the Project Work Breakdown Structure as a result of their joining the Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O or M&O); add participants to Work Breakdown Structure elements 1.2.3.2.8.3.3, Ground Motion from Regional Earthquakes and Underground Nuclear Explosions, and 1.2.3.9.7, Exploratory Studies Facility and Surface-Based Testing Coordination; and add new Work Breakdown Structure elements 1.2.1.11, Determination of Importance Evaluation, 1.2.5.7, Site Activities Evaluation and Review, and 1.2.15.5, YMSCO Safeguards and Security Program Development.

Systems Engineering Management Plan

The Systems Engineering Management Plan (DOE, 1994j) describes the implementation of the systems engineering process on the YMP. This document was issued during the reporting period to incorporate changes in the Program-level Systems Engineering Management Plan (DOE, 1994k).

Regulatory Compliance Plan

The Regulatory Compliance Plan (DOE, 1990b) has not undergone any changes during this reporting period.

Forecast: In FY 1995 the following changes are expected: a major revision of the Configuration Management Plan, a revision to the Environmental Management Plan, a revision of the Systems Engineering Management Plan as a result of the implementation of the new Program Approach, and a major revision of the Regulatory Compliance Plan.

2.1.4.3 Site Characterization Program Baseline

The Site Characterization Program Baseline (DOE, 1994a) documents information on the integration of the Exploratory Studies Facility with the Geologic Repository Operations Area and presents a high-level description of the test program and the physical relationship of the test facilities to the potential repository. All revisions to the Site Characterization Program Baseline are reviewed, approved, and controlled in accordance with approved change

control procedures. Revision history for the Site Characterization Program Baseline is provided in Table 2-2 for information.

Revision 11, issued August 3, 1994, consisted of a revision to Investigation 8.3.1.8.2, Studies to Provide Information Required to Evaluate Changes in the Natural and Engineered Barrier System Resulting from Tectonic Events. The objectives of Activity 8.3.1.8.5.2.1, Evaluation of Depth of Curie Temperature Isotherm; Activity 8.3.1.8.5.2.3, Heat Flow at Yucca Mountain and Evaluation of Regional Ambient Heat Flow Anomalies; and Study 8.3.1.17.3.1, Relevant Earthquake Sources, were also revised. Editorial changes to Section 8.4 were documented.

Forecast: During FY 1995, it is expected that a revision to the Site Characterization Program Baseline will be prepared to remove the testing objectives and baseline physical facility configurations. Testing objectives that are now baselined in the Site Design and Test Requirements will be removed from the Site Characterization Program Baseline. The Site Characterization Program Baseline will be revised to document current Exploratory Studies Facility, Surface-Based Testing Facilities, Repository, and Engineered Barrier System concepts.

2.1.4.4 Change Control Board Actions

The Project Change Control Board evaluates proposed changes to the Project Baseline. If the proposed change is approved, the change is implemented by the Affected Organization in accordance with the directions listed in the change directive.

Appendix D is a table summarizing the Project Change Control Board actions during this reporting period that affected the baseline documents or activities regarding requirements, Exploratory Studies Facility, and Surface-Based Testing. Of the change requests processed during this period, the most noteworthy is the revised Exploratory Studies Facility Cost Estimate (CR 94/317) which was an update addressing and aggregating numerous changes over a significant period.

2.2 REGULATORY ACTIVITIES

As described in Chapter 1, the new Program Approach is intended to bring the program back to the original intent of the legislative and regulatory framework. Regulatory activities, including the development of product outlines and interactions with oversight organizations, identify the information needed from site characterization, design, and performance assessment activities to achieve the objectives of the Program Approach. Progress in the regulatory activities associated with site suitability, environmental compliance, and licensing activities to prepare for Program Approach implementation is reported in this section.

Table 2-2. Site Characterization Program Baseline History

Revision	Issued	Revisions
0	2/22/91	Initial Issue
1	4/5/91	Updated information related to the Exploratory Studies Facility. Incorporated changes to program planning resulting from the "Exploratory Studies Facility Alternatives Study: Final Report."
2	10/2/91	Revised plans for testing in Site Characterization Plan Section 8.3.1.14. Consolidated all of the anticipated studies under Investigation 8.3.1.14 into one Study Plan (8.3.1.14.2).
3	2/7/92	Changes to the objectives of Activities 1 and 4 in Study Plan 8.3.1.2.1.4 and Activity 4 in Study Plan 8.3.1.2.3.2. Added three drillholes to Study Plan 8.3.1.2.3.1. Deleted requirement for tagging surface dust suppression water with chemical tracer.
4	3/13/92	Incorporated changes in the objectives of Activities 1 and 3 in Study Plan 8.3.1.2.3.2.
5	7/15/92	Corrected references to integration of geophysical activities.
6	7/15/92	Updated Section 8.4 to be consistent with current Exploratory Studies Facility concept.
7	7/15/92	Deleted Activity 8.3.1.4.2.1.6.
8	9/24/92	Reorganized waste package near-field environment program.
9	10/2/92	Changed scope of the Site Characterization Program Baseline to delete activity descriptions that are controlled in the study plans; placed parameter tables in separate controlled document; removed hypothesis testing tables and analyses supporting test control from the Site Characterization Program Baseline. Changes made to Activities 8.3.1.2.2.4.6, 8.3.1.5.2.1.2, 8.3.1.5.2.2.1, 8.3.1.5.2.2.2, 8.3.1.5.2.2.3; changes made to Studies 8.3.1.3.7.2, 8.3.1.8.1.1, 8.3.1.8.1.2, 1.10.4.3; and changes made to Investigation 8.3.1.7.1.
10	1/14/93	Documented changes made to Study 8.3.1.2.2.4; Activities 8.3.1.8.5.2.2, 8.3.1.15.2.2, 8.3.1.17.4.3.2, 8.3.1.17.4.4.3; and Section 8.3.5.13.
11	8/3/94	Revised Investigation 8.3.1.8.2. Revised the objectives of Activities 8.3.1.8.5.2.1, 8.3.1.8.5.2.3, and 8.3.1.17.3.1. Documented editorial changes to Section 8.4.

2.2.1 Site Suitability Activities

The site suitability evaluation process calls for the separate evaluation of individual guideline conditions, or groups of guideline conditions, specified in 10 CFR Part 960 leading to an overall site suitability evaluation, as described in Section 1.3.1. A proposed site suitability evaluation schedule for each interim evaluation and groupings of guidelines is provided in Appendix A. These evaluations will be made as the relevant site characterization data, analyses, facility designs, and nongeoscience data become available. The DOE will first develop a technical basis report that discusses the current state of understanding in a defined technical area. Then, using the relevant technical basis report and the comments from an independent external peer review of the report, DOE will develop a guideline compliance assessment for each guideline, ultimately leading to a comprehensive Technical Site Suitability Evaluation in 1998.

The Program Approach was designed to ensure that DOE makes efficient, measurable progress toward a decision about the suitability of Yucca Mountain as a repository site. As part of this restructured program, DOE has developed an open and sequential process for evaluating Yucca Mountain suitability that will document the evidence and the rationale for DOE decisions.

The DOE has held extensive discussions with the Program's stakeholders about the suitability evaluation process over the past several years. Development of the process that will begin to be implemented during FY 1995 has been subject to more recent public review through written comments, meetings and workshops, and to revision on the basis of that review. Interactions with the public and oversight groups on development of the site suitability evaluation process during the reporting period have included:

- Federal Register Notice of Inquiry (59 FR 19680) on April 25, 1994, requesting the views of members of the public regarding the process for evaluating site suitability

- A public workshop on May 21, 1994, in Las Vegas, Nevada, that sought stakeholder ideas and views on the suitability evaluation process

- Periodic status briefings to the Affected Units of Government at their regularly scheduled meetings. These briefings were a follow-up to meetings with the Affected Units of Government during the previous reporting period

- Public Workshops on August 27, 1994, in Las Vegas, Nevada, and August 30, 1994, in Washington, D.C., to discuss the draft process for evaluating site suitability

- An August 4, 1994, Federal Register notice (59 FR 39766) announcing the DOE decision to use the Siting Guidelines as they currently exist and requesting views of members of the general public on a draft description of the process for evaluating the suitability of the Yucca Mountain site

- Meetings with NRC management on July 26 and September 21, 1994, to discuss the process and the relationship to licensing. On the basis of this external consultation, DOE is finalizing its process for evaluating the suitability of the Yucca Mountain site for development as a geologic repository.

The process also provides for predecisional public involvement at key points in the evaluation sequence. The DOE is negotiating a contract with NAS to manage a process of external peer review of the technical basis reports. The external and stakeholder communities will be asked to nominate candidates for peer review, present technical issues to the peer review panel for consideration, and will be able to observe all public meetings of the peer review panels. The peer review will only evaluate the technical basis reports. The DOE will seek public comments and hold public workshops on the guideline compliance assessments that are developed following review of the technical reports.

Forecast: The process for evaluation of site suitability is expected to be defined in November 1994 and public meetings will be held to brief stakeholders on the final process in December 1994. In response to comments from the public at the August 1994 stakeholders meetings on the process, DOE will publish a draft of the proposed work scope for the NAS Board on Radioactive Waste Management defining their role in managing the external peer review of the DOE technical basis reports. The DOE will also develop preliminary outlines for each technical basis report. These outlines will be used to help plan appropriate resources in the Site Characterization Program to focus site investigations on the studies that should be completed to finish the technical basis reports. In addition, development of the technical basis report for surface-disturbing processes will be initiated.

2.2.2 Environmental Compliance Activities

Environmental compliance activities include the development of an Environmental Impact Statement to accompany any Site Recommendation Report to the President. In addition, environmental preactivity surveys, audits, land acquisition, and permitting activities are prerequisites to performing any site characterization work in the field. The progress in these areas is reported in this section.

2.2.2.1 National Environmental Policy Act

The Nuclear Waste Policy Act, as amended, requires that the recommendation for repository development be accompanied by an Environmental Impact Statement. The Environmental Impact Statement will be prepared in compliance with the National Environmental Policy Act, as directed by Congress in the Nuclear Waste Policy Act. The scope of the Environmental Impact Statement will integrate data from design, site suitability, licensing, transportation, systems safety and ongoing environmental monitoring data collection, as necessary, to evaluate the impacts of locating a potential repository at Yucca Mountain.

The major elements of the Environmental Impact Statement begin with issuance in the Federal Register of a Notice of Intent to prepare an Environmental Impact Statement. The Notice of Intent begins the public scoping process that will include numerous public meetings intended to obtain the public's input on what issues should be addressed in the Environmental Impact Statement.

A Draft Environmental Impact Statement will be issued for public review and comment. Once comments have been addressed, a Final Environmental Impact Statement will be published. The Notice of Intent is currently scheduled to be issued in mid 1995, with the Draft Environmental Impact Statement scheduled for 1998, and the Final Environmental Impact Statement and Record of Decision scheduled in 2000.

2.2.2.2 Permits

Permits are required for some land use activities with potential environmental impacts. This section provides a discussion of the progress/activity on such permits during the reporting period.

Water Quality

A request for approval to use a portable bathroom/holding tank facility was submitted to the State. The Nevada Department of Health requested several modifications to the design. These changes were made and the design drawings were being updated. The system was tested and approval is expected by October 1994.

A request was submitted to the Nevada Department of Health to place a motorized recreational vehicle as a temporary medical facility at UE-25 J#13. The recreational vehicle will be replaced by a permanent facility within one year. Approval was granted in September 1994.

A temporary water appropriation permit changing the place of use for trenching activities was filed in July and approval is expected in October 1994.

Air Quality

On May 26, 1994, the Nevada State Environmental Commission adopted the Bureau of Air Quality's Title V Program, which had been submitted to the U.S. Environmental Protection Agency (EPA), Region IX. In addition to changing the fee structure to an annual fee for air quality permits, all permits issued after July 1, 1994, will be Air Quality Operating Permits. Air Quality Permits to Construct will no longer be issued.

Air Quality Operating Permits were received for the following drill rig/dust collector systems in August 1994: Top Head Drive Core (Model B-8022), Top Head Drive Core (Model Bratt-22), and CME-85. A request for an Air Quality Permit for a rock crushing plant was submitted in May and approval is expected in October 1994.

Drilling and Tracers

A Waiver to Drill was requested for USW SD-9 in March, and approval was received in May 1994. A Waiver to Drill and a Request for Tracer Use for USW UZ-7a were submitted in September and June 1994, respectively. Approval of the waiver request is pending; tracer use was approved in June 1994. A Request for Tracer Use for USW SRG-3 and SRG-3a was submitted and approval granted in August 1994. Approval to use tracers for the seismic reflection studies was received in September 1994.

Forecast: The YMP permit applications/modifications projected to be submitted over the next six months include: Air Quality Operating Permits for the muck conveyer system and four additional drill rigs, modifications to the Underground Injection Control Permit to increase the number of boreholes for tracer injection and to request the use of additional tracers, four tracer injection approvals under the Underground Injection Control Permit, a sewage disposal permit, and a mine wastewater permit.

2.2.2.3 Environmental Audits

Environmental audit activities during this reporting period consisted of two comprehensive environmental audits and three Focused Special Issue Audits. The two Project participants that were the subjects of the comprehensive environmental audits were CRWMS and LLNL. The LLNL audit was combined with Safety and Health to establish the first YMP consolidated environmental, safety, and health audit. All future comprehensive audits will be environmental, safety, and health audits.

The three Focused Special Issue Audits conducted were:

- Air Quality Permit Compliance at the YMP
- Environmental Readiness for Tunnel Boring Machine Activities
- Environmental Technologies, Inc. Waste Management Operations and Procedures.

Forecast: Two comprehensive environmental, safety, and health audits and two Focused Special Issue Audits are scheduled to be completed within the next six months. The next participant designated for a comprehensive audit is Los Alamos.

2.2.2.4 Environmental Surveillance

During this period, approximately 300 environmental surveillances were conducted at the Yucca Mountain site to ensure compliance with environmental, programmatic, and permit requirements. Corrective action and follow-up work was required on 28 percent (84) of the surveillances; and 67 percent (56) of those follow-up activities were completed.

Forecast: The number of surveillances projected over the next six months is approximately 350.

2.2.2.5 Preactivity Surveys

Completion of 13 land access and environmental compliance activity reviews contributed to the overall progress accomplished on the YMP during this period. This effort involved the acquisition of required land access approvals and right-of-way reservations and completion of 39 radiological, archaeological, and biological surveys prior to commencement of specific YMP site activities. An additional 13 requests to initiate preactivity surveys were received during this period. There are currently 18 "open/active" field activities, for which environmental preactivity surveys are being, or will be, conducted.

Forecast: It is anticipated that approximately 15 land access and environmental compliance activity reviews will be completed in the next six months. This effort will involve an estimated 45 radiological, archaeological, and biological preactivity surveys.

2.2.2.6 Land Acquisition and Site Access

The significant land acquisition event of this period was the granting of an extension to Right-of-Way Reservation N-48602 by the Bureau of Land Management (BLM). This Right-of-Way Reservation on the Nellis Air Force Base Range now has an expiration date of January 6, 2001, which coincides with Right-of-Way Reservation N-47748, the large BLM Right-of-Way Reservation to the west of the Nevada Test Site. Many site characterization activities take place on these two reservations.

A participant request to initiate a site activity is a prerequisite for the activity. Five new participant requests to initiate site characterization activities were received during this reporting period. Two of these, Construction of Subsurface Wastewater Pond and Rock Valley Test Pits, have been completed and access authorization granted. The remaining three are in process.

One request from the last reporting period, Seismic Reflection Program, has been completed with the granting of a Right-of-Way Reservation from BLM. Three requests, for Volcanism Studies at Sleeping Butte and Crater Flat and Quaternary Faulting Studies in Crater Flat, are awaiting Right-of-Way Reservation grants.

A continuing problem has been the inordinate amount of time required by BLM to process Right-of-Way Reservation applications. Many have taken well over a year for seemingly simple requests. Through meetings, it has been determined that lack of BLM staff and the requirement that they prepare environmental assessments for each Right-of-Way Reservation are the cause of the delays. The YMSCO has volunteered to prepare these documents in the future to help alleviate this problem.

2.2.3 Licensing Activities

Licensing activities include the management of and participation in interactions with NRC and other oversight organizations to clarify regulatory and technical issues and reach a common understanding of regulatory requirements. DOE has developed and implemented an Issue Resolution process to aid in the identification, clarification, and resolution of technical and regulatory issues raised by NRC during site characterization. The License Application Annotated Outline process was revised and rescheduled to implement the licensing strategy outlined in the Program Approach.

2.2.3.1 Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations

This section reviews and discusses significant actions, agreements, and accomplishments achieved during the reporting period from twelve interactions between DOE and NRC, seven with the Advisory Committee on Nuclear Waste (ACNW), five with NWTRB, and one with NAS. Acknowledgement of these significant activities is necessary to plan and implement site characterization and design studies successfully. Appendix B provides an all-inclusive list of interactions with each of the following agencies.

U.S. Nuclear Regulatory Commission

The new Program Approach was of particular interest to NRC during the reporting period. At the May 19, 1994 management meeting, NRC staff provided positive feedback on the Program Approach and stated that the Program Approach was not inconsistent with the flexibility inherent in 10 CFR Part 60. At a July 26, 1994, management meeting, DOE Program Approach and Issue Resolution topics were discussed. The DOE discussed the interface between licensing (10 CFR Part 60) and site suitability (10 CFR Part 960) under the Program Approach. The NRC management provided its preliminary views on how it might review the Program Approach (e.g., activities and products) with respect to 10 CFR Part 60 requirements.

The Exploratory Studies Facility design control and related Quality Assurance (QA) activities were also significant concerns of NRC staff. At the April 19 and July 27, 1994, DOE-NRC Exploratory Studies Facility Design and Construction Technical Meetings, DOE presented explanations of the design document hierarchy and the Site Characterization Program Baseline for NRC staff to illustrate design requirements traceability. Additionally, following the Exploratory Studies Facility Design Package 2C Reviews, NRC expressed renewed concerns with regard to Exploratory Studies Facility design control and QA. A DOE-NRC QA Meeting was conducted August 31, 1994, to discuss continuing NRC concerns and corrective actions necessary to alleviate those concerns.

During a September 21, 1994, management meeting, the multi-purpose canister and burnup credit were discussed. The NRC clarified that the technical review period for the

multi-purpose canister certification will last 18 months, and an additional year will be required to undertake a rulemaking for adding the multi-purpose canister to the list of approved spent fuel storage casks in 10 CFR Part 72, Subpart K.

At the September 21, 1994, meeting, DOE explained a plan to consolidate Site Characterization Plan study plans in response to the Proposed Program Approach and with the intent to achieve greater efficiencies in the site characterization planning documentation the Program provides. A list of Site Characterization Plan sections that have yet to have study plans developed was identified for one or a combination of actions to be taken. Among the potential actions are (1) transfer or aggregate the work scopes to other existing or yet to be written study plans that are natural homes for this work or that could be expanded with minimal effort to include this work, (2) report work that has already been completed in a technical report or DOE working paper, and (3) present other rationale for why a study plan need not be developed.

The rationale for these pending study plan actions may include, but is not restricted to, the following examples: (1) describes small work scope; (2) describes work scope that was substantially complete even when the Site Characterization Plan was written; (3) describes work more appropriately done under other management controls; (4) describes work that compiles, collects, or reformats existing documentation; or (5) describes analyses or syntheses conducted on data collected from other Site Characterization Plan studies to provide various recommendations. The study plans affected by these actions are listed in Appendix E and the rationale for DOE's actions are discussed in Sections 3.2 through 3.12. The Site Characterization Program Baseline and the Site Design and Test Requirements document are currently in the process of revision to accommodate these changes.

Advisory Committee on Nuclear Waste

As with NRC, the new Program Approach was of interest to ACNW. The NRC staff provided a review of the Program Approach to ACNW at the 66th meeting in Rockville, Maryland on August 16, 1994. The 67th ACNW meeting, conducted in Rockville, Maryland on September 21, 1994, included a presentation by the Project on the Program Approach. The ACNW concerns included (1) limited scope of study plans and lack of comprehensive data for use in site suitability determinations and a License Application, (2) increased uncertainties at time of License Application for a construction authorization, (3) shortened schedule for site characterization, (4) separation of licensing issues from site suitability issues, (5) need for bounding assumptions for site suitability based on incomplete data, (6) need for increased use of expert judgment by NRC to assess licensability, and (7) decreased NRC authority over DOE prelicensing decisions.

During the reporting period, ACNW also focused on NRC and the Center for Nuclear Waste Regulatory Analysis capabilities to assess the site characterization program and site suitability and licensing issues; tectonics, volcanism, and geology; the Extreme Erosion Topical Report (DOE, 1993b) and the NRC staff's review of that report (NRC, 1994a); and NRC staff discussions on substantially complete containment.

Commissioner Rogers addressed the ACNW on expert judgment and recommended that use of expert judgment be expanded. He tasked ACNW with development of criteria for use or nonuse of expert judgment and to consider (1) an increase in the quality of the NRC staff knowledge base and (2) maintenance and retention of an NRC review system throughout long-term projects.

Nuclear Waste Technical Review Board

The NWTRB Structural Geology and Geoengineering Panel meeting was held in Las Vegas, Nevada, in June 1994. Specific topics discussed at the meeting included the DOE Program Approach and how it could affect the schedule for testing, site suitability issues, and the key assumptions used for the repository Advanced Conceptual Design. The NWTRB questioned whether DOE would be able to meet the Program Approach schedule.

In addition to DOE Program Approach discussions, the NWTRB Hydrogeology and Geochemistry Panel meeting was held in Las Vegas, Nevada, September 12-13, 1994. The focus of the meeting was ground-water travel time and its relative importance to long-term repository performance. Presentations addressed the original intent of 10 CFR Parts 60 and 960, the technical basis for the 1000-year containment criterion, and the DOE general approach to satisfying ground-water travel time requirements. The NWTRB noted a potential need to use expert judgment where insufficient data are available to make determinations, as in the case of ground-water travel time, and reiterated a concern with expert judgment use because there are no clear guidelines at this time.

National Academy of Sciences

At the request of NAS, DOE designated a technical liaison representative to the NAS Committee on Technical Bases. In addition, the Program formed a task force to monitor activities associated with developing a standard for Yucca Mountain, and to provide input to the NAS committee. The task force developed recommendations to NAS on a standard for Yucca Mountain, and those recommendations were provided to NAS by letter on April 8, 1994 (DOE, 1994m). The following excerpt summarizes the DOE recommendations.

> It is the recommendation of the DOE that a standard for Yucca Mountain should be based on the protection of those people living in the vicinity of the potential repository. The standard should be health-based and commensurate with other radiation protection standards. A quantitative demonstration of compliance should be provided, supplemented by qualitative arguments to provide reasonable assurance, based on the weight of the evidence presented, that the protective limits will not be exceeded. Probabilistic analyses should be used in the quantitative demonstration of compliance. The standard or associated guidance should include specification of assumptions pertaining to the biosphere for use in quantitative calculations. These biosphere assumptions should be based on the current level of technology and the living habits of people now residing in the vicinity of Yucca Mountain. Human intrusion scenarios should be treated in a qualitative, not quantitative, manner.

No further interactions with the NAS Committee on Technical Bases for Yucca Mountain Standards are anticipated prior to the publication of the NAS report.

2.2.3.2 Issue Resolution

The OCRWM has developed and implemented a resolution process to aid in the identification, clarification, and resolution of technical and regulatory issues raised by the NRC during site characterization. This process was developed based upon the "Issues-Based Approach to Planning Site Characterization" contained in the Site Characterization Plan (p. 8.1-1). Issue Resolution is directed toward determining the definition and interpretation of regulatory terms, acceptability of site characterization methodologies, and adequacy of site characterization planning and acquired data and analyses as required by 10 CFR Part 60. Although an issue is not considered "closed" during the prelicensing period, and any issue can be revisited based on new information, it is important for DOE to seek clarification and early resolution with NRC staff on as many areas of uncertainty as possible. This clarification is accomplished by frequent interactions and communications with NRC and its staff. These interactions may include reports sent to NRC staff for review and comment (e.g., topical or technical reports), letters, submittals of the License Application Annotated Outline (see Section 2.2.3.3), or meetings between DOE and NRC.

Resolution of the Site Characterization Analysis (NRC, 1989) open items is being coordinated within the Issue Resolution process. Resolving NRC open items is a bilateral process that consists of (1) OCRWM providing documentation or other basis to NRC to resolve specific items, and (2) NRC accepting (or not accepting) the basis for resolution, and informing OCRWM. Both steps are needed to remove open items from further consideration.

Issue Resolution activities during the reporting period included the following.

Seismic Hazards

The DOE transmitted Seismic Topical Report I (DOE, 1994n) to NRC on June 30, 1994. This report provided a description of the methodology for assessing seismic hazard levels for design. The NRC provided a letter dated September 7, 1994 (NRC, 1994b), stating that the report did not meet the criteria of their Topical Report Review Plan (NRC, 1994c), and therefore would not initiate a review. During a DOE-NRC Management Meeting on September 21, 1994, DOE and NRC agreed to conduct a Technical Exchange on October 7, 1994, to discuss NRC concerns and actions to resolve the concerns. The DOE developed and submitted to NRC an annotated outline for a second seismic topical report on August 22, 1994. This report will establish seismic safety categories for systems, structures, and components at Yucca Mountain, associated seismic safety performance goals and risk reduction factors, and seismic design criteria to achieve the performance goals and risk reduction. A third Seismic Topical Report is also planned. This report will describe the development of seismic design inputs (seismic response spectra, time histories, and fault displacement level, etc.) for the appropriate seismic hazard levels.

Substantially Complete Containment

The DOE proposed a new performance goal as a means of demonstrating compliance with the substantially complete containment provisions of 10 CFR Part 60. This approach is being documented as part of the DOE efforts to resolve Site Characterization Analysis open items. The DOE submitted supplemental responses on open items related to substantially complete containment to NRC by letters dated March 30, 1994 (DOE, 1994o), May 17, 1994 (DOE, 1994p), and June 10, 1994 (DOE, 1994q). In response, by letter dated July 11, 1994 (NRC, 1994d), NRC stated, "In principle, the NRC staff considers that the new DOE performance goal is a reasonable implementation of the substantially complete containment requirement." The NRC went on to state that Site Characterization Analysis Comment 5 and Question 46 are considered resolved, Comment 80 is partially resolved, but Question 47 remains open. The DOE provided supplemental information pertaining to the remaining open items by letter dated September 20, 1994 (DOE, 1994r). A Technical Exchange has been scheduled for December 7, 1994, to further discuss waste package design and substantially complete containment.

Absence of Extreme Erosion

The DOE briefed ACNW on the Extreme Erosion Topical Report on August 16-17, 1994. The DOE received the results of the NRC staff review of the topical report in a letter dated August 22, 1994 (NRC, 1994a). The NRC indicated that the scope of the topical report was inappropriate, the adequacy of the dating method was not demonstrated, and the data qualification process was deficient. During a DOE-NRC Management Meeting on September 21, 1994, a Technical Exchange was scheduled for October 7, 1994, to discuss NRC concerns and resolution of the concerns.

Ground-Water Travel Time

The DOE developed a general approach to calculation of ground-water travel to evaluate compliance with 10 CFR 60.113(a)(2), the performance objective for the geologic setting, and to evaluate compliance with the ground-water travel time disqualifying condition in the DOE general siting guidelines (10 CFR Part 960). The general approach was outlined to NWTRB at its April 12, 1994, spring meeting. The approach outlined the DOE view that: travel time is a distribution of water particle transport times between the disturbed zone and the accessible environment; the significance of travel times less than 1000 years would have to be evaluated based on performance assessment; the disturbed zone is defined as the zone of altered transport parameters, which has a significant effect on postclosure performance; and that uncertainties in travel times would have to be evaluated. The NWTRB expressed agreement with the general approach.

The DOE submitted a written description of the general approach to NRC for review and comment on June 10, 1994 (DOE, 1994s). The NRC responded by letter dated August 23, 1994 (NRC, 1994e). The NRC generally agreed with the approach outlined above and agreed with DOE that more detailed discussion of the disturbed zone was necessary. The NRC also requested more detail on incorporation of uncertainty, more discussion of the

determination of significance of short travel times, more detail on the use of matrix diffusion and dispersion, and discussion of the convolution of the unsaturated and saturated travel-time distributions. They suggested that these details could be discussed at the November 1994 DOE-NRC Technical Exchange.

The DOE formed a Ground-Water Travel Time Working Group to provide technical and regulatory advice to the Program participants involved in the calculation of ground-water travel time. This working group was also charged with developing the DOE approach to calculation of ground-water travel time, based on the approach outlined to NWTRB and NRC. A more detailed approach was developed through interaction among the following participants: Sandia National Laboratories (SNL), U.S. Geological Survey (USGS), and the M&O. This approach reflects the NRC response in the August 23, 1994 letter, and is consistent with the DOE Program Approach. It was presented to the NWTRB Hydrology and Geochemistry Panel at their September 12-13, 1994, meeting. The NRC also expressed agreement with the more detailed approach. (For more discussion on calculational aspects of ground-water travel time see Chapter 6, Section 6.5.4.)

Engineered Barrier System

The DOE agrees with the NRC definition that the Engineered Barrier System does not extend into the host rock, and documented this position on April 21, 1994 (DOE, 1994t).

Resolution of Site Characterization Analysis Open Items

The Project continues to work toward resolving the open items from the Site Characterization Analysis (NRC, 1989). During the reporting period, OCRWM provided supplemental responses to Comment 5 and Questions 3, 46, and 56 on May 17, 1994 (DOE, 1994p), Question 47 on June 10, 1994 (DOE, 1994q), Comment 36 and Questions 5 and 20 on June 16, 1994 (DOE, 1994u), and Questions 35, 45, and 51 on July 1, 1994 (DOE, 1994v). In addition, NRC staff agreed that OCRWM provided the technical basis to resolve Comment 123 in a letter dated June 21, 1994 (NRC, 1994f), and Comment 5 and Question 46 in a letter dated July 11, 1994 (NRC, 1994d).

As of the end of this reporting period, 85 open items have been closed (including two objections) and 113 remain open. The majority of the remaining open items await data to be acquired through site characterization activities for their resolution. Of the 113 remaining open items, 32 were being reviewed by NRC staff after DOE submitted supplemental responses.

Appendix C presents the status of Site Characterization Analysis comment resolution. For each open item, actions that need to be performed to close the item are identified. Open items will continue to be resolved as site characterization and other programmatic activities provide pertinent information.

Resolution of Progress Report Comments and Questions

During this reporting period the Project received no new comments or questions from NRC staff on Progress Reports. A staff evaluation (NRC, 1994g) was received which closed Question 1 on Progress Reports #6 (DOE, 1992c) and #7 (DOE, 1993c).

As of the end of this reporting period, 19 observations, two comments, and three questions have been closed; two comments and five questions remain open. Of the open items, five from Progress Report #8 (DOE, 1993d) and two from Progress Reports #6 and #7 were awaiting NRC staff verification of responses.

Forecast: During the first half of FY 1995, DOE intends to accomplish the following through the Issue Resolution process: (1) pursue resolution of NRC concerns relative to their refusal to perform a review of Seismic Topical Report I; (2) conduct a Technical Exchange on substantially complete containment, and follow up with a supplemental response to Site Characterization Analysis Comment 80 and Question 47; (3) pursue resolution of the comments and concerns from the NRC review, and receive an NRC safety evaluation of the Extreme Erosion Topical Report; (4) develop an Issue Resolution Action Plan and conduct a Technical Exchange to provide a description of the proposed methodology for determining ground-water travel time; (5) transmit to NRC, for information, the final technical report (Crowe et al., in prep.) on the status of volcanic hazards investigations at the proposed Yucca Mountain repository; and (6) continue to pursue resolution of remaining Site Characterization Analysis open items.

2.2.3.3 License Application Annotated Outline

During this reporting period, a draft of Revision 4 of the License Application Annotated Outline (DOE, in prep.[d]) was prepared. The draft consisted of a revision to Chapter 6, Overall System Performance Assessment, to incorporate Total System Performance Assessment - 1993 (Andrews et al., 1994; Wilson et al., 1994) and to Chapter 3, The Natural Systems of the Geologic Setting. In addition to this original scope, both the design and performance assessment sections in Chapter 5, Engineered Barrier System, were revised to incorporate the multi-purpose canister concept.

This draft of Revision 4 was developed prior to the major program redirection embodied in the Program Approach. The review draft of the Mined Geologic Disposal System Annotated Outline Skeleton Text for the Preparation of a License Application, Revision 4, was completed on schedule. Because the License Application Annotated Outline process has a key role in Program Approach implementation, Revision 4 was revised to incorporate the Program Approach strategies for licensing, converted to a DOE document and rescheduled for delivery as Revision 0 to NRC on March 31, 1995.

A draft unified licensing strategy consistent with the Program Approach and the multi-purpose canister has been developed for incorporation into the License Application Annotated Outline. The licensing approach, in conjunction with the License Application Annotated

Outline information needs, provides a framework for categorizing the information necessary for the initial license application.

Forecast: License Application Annotated Outline Revision 0 will be delivered to NRC by March 31, 1995.

2.3 QUALITY ASSURANCE

During this reporting period, notable progress has been accomplished in the transition to the new Quality Assurance Requirements and Description (DOE, 1992d), resulting in the acceptance of several participant QA programs through audits and surveillances. Determination of Importance Evaluations were performed to classify and grade structures, systems, and components prior to site-disturbing activities, resulting in changes to the Q-List. This section reports progress in these and other QA activities.

2.3.1 Program Activity

The Office of Quality Assurance issued the new Quality Assurance Requirements and Description in December 1992. This document is the principal QA document for the Civilian Radioactive Waste Management Program. The Quality Assurance Requirements and Description contains regulatory requirements and program commitments necessary for the development of an effective quality assurance program. The QA implementing documents must be based on, and be consistent with, Quality Assurance Requirements and Description requirements.

Significant progress was made in the transition to the new Quality Assurance Requirements and Description by Affected Organizations. The following QA Programs were accepted during the reporting period:

USGS
Technical and Management Support Services
SNL
LLNL

The DOE/Office of Quality Assurance, Yucca Mountain Quality Assurance Division, conducted eight audits during this reporting period. Audits are planned and documented verification activities which evaluate compliance with requirements and determine effectiveness of implementation through a review of objective evidence. The following organizations were subject to audit:

Reynolds Electrical & Engineering Co., Inc.
Technical and Management Support Services
USGS
CRWMS M&O

Los Alamos
SNL
LLNL

Audit results indicate that all organizations, with the exception of the M&O, are satisfactorily implementing the QA Program. The audit of the M&O determined that the Design Control Program was not effectively implemented. The audit identified issues related to the M&O QA program and the DOE role in the oversight of the M&O program. The concerns resulted from deficiencies identified by DOE during QA audits and surveillances of the M&O design process and on independent design reviews of Design Packages 2A and 2B performed by DOE and its contractors. Corrective actions were identified in a response to concerns related to this audit by the NRC after the reporting period.

In addition to audit activities, the Yucca Mountain Quality Assurance Division conducted 28 surveillances during the reporting period. Surveillances are observations of real-time quality affecting activities and/or the review of documentation to verify conformance with specified requirements. The surveillances evaluated specific site characterization activities including the adequacy and effectiveness of corrective actions taken to resolve previously reported conditions.

Quality Assurance Divisions for the organizations supporting DOE conducted many verification activities during this reporting period. The Affected Organizations performed 53 audits and 84 surveillances on internal and external organizations.

Forecast: The Office of Quality Assurance will be undergoing a transition in FY 1995. Audit and vendor survey activities performed by Affected Organizations will be transitioned to the Office of Quality Assurance. Upon completion of the transition, the Office of Quality Assurance will retain responsibility for all OCRWM audits and vendor surveys. This streamlining effort will benefit OCRWM financially and programmatically by providing consistency in all oversight functions.

2.3.2 Determination of Importance Evaluations

A Determination of Importance Evaluation is the mechanism established by the YMP for classification and grading of structures, systems, and components. This evaluation is conducted as an engineering analysis that invokes the classification of permanent items (i.e., items that are assumed to have a function in an operating repository). When a permanent item is identified as meeting the classification criteria, that item is recommended for placement on the Yucca Mountain Q-List (see Section 2.3.3).

The Determination of Importance Evaluation procedure is also used to evaluate the potential impact of site-disturbing activities. Activities, which include site characterization activities involving the use of temporary items, are evaluated with respect to their potential adverse impacts on permanent items on the Q-List, including the natural barrier. Based on these potential impacts, appropriate controls are established for the associated activities.

As part of the planning process for testing and construction activity, site impact assessments in the form of Test Interference Evaluations and Waste Isolation Evaluations are performed. These evaluations address the potential of site characterization activities to interfere with ongoing or planned tests, and to affect the ability of the site to isolate waste. Potential test interference or waste isolation concerns are addressed through imposition of controls on testing, design, construction, or operations activities.

During this reporting period, the following Determination of Importance Evaluations were produced. Each Determination of Importance Evaluation corresponds to one or more input Waste Isolation Evaluation and Test Interference Evaluation.

Exploratory Studies Facility Determination of Importance Evaluations

ESF Package 2C (North Ramp - including tunnel boring machine operation)
ESF North Portal Pad (Rev. 4)
ESF Subsurface Wastewater and Sanitary Sewer Collection System (Rev. 1)
ESF Muck Storage Area and Access Road
ESF Integrated Data and Control System

As part of the consolidation discussed above, the first Determination of Importance Evaluations for Surface-Based Testing activities were conducted during this reporting period.

Surface-Based Testing Determination of Importance Evaluations

USW SD-7 Borehole, Access Road and Drill Pad
UE-25 UZ#16 Grout Test
USW UZ-7a Access Road and Drill Pad
Unsaturated Zone Instrumentation of USW NRG-6 and USW NRG-7a

Examples of QA controls resulting from these evaluations are limits on water use during construction and operation, discharge of organics during underground construction, prohibition on use of materials to limit test interference impacts (e.g., salt for electrical grounding), etc. Various QA controls are also applied to conventional excavation and construction techniques, to ensure they are conducted in such a way as to limit potential geomechanical, geochemical, or hydrologic impacts to the site.

In addition to formal Determination of Importance Evaluations, several other evaluations have been conducted to determine that a Determination of Importance Evaluation was not required, or to provide for review of procurement specifications in advance of Determination of Importance Evaluations associated with in-progress design packages. The evaluations performed during this reporting period included:

USW NRG-7a Reaming (borehole rework evaluation)
Seismic Reflection Testing evaluation
USW NRG-6 Reaming (borehole rework evaluation)

UE-25 UZ#16 Rework evaluation
Procurement Evaluation for tunnel boring machine
Procurement Evaluations for rolling stock, precast inverts, various surface and subsurface utilities, and conveyor.

Forecast: Further revision to the Determination of Importance Evaluation line procedure is anticipated to delete Waste Isolation Evaluations and Test Interference Evaluations as discrete documents (i.e., input will be directly into the Determination of Importance Evaluation, which will be produced as a single document), thereby making the site impact evaluation process more efficient. A DOE Project-level procedure is also planned to be issued in the next reporting period; this procedure will provide guidance to participants in the implementation of the Tracers, Fluids, and Materials Management Plan (DOE, 1993e).

2.3.3 Q-List and Management Control List

The Project Q-List (DOE, 1990c) and Management Control List (DOE, 1994w) are used to tabulate permanent items (i.e., items which may become part of a licensed pre- or postclosure repository). The Q-List describes those permanent items determined to be important to radiological safety, important to waste isolation, or otherwise subject to the requirements of the Quality Assurance Requirements and Description, Section 2.2.3A. The Management Control List describes those permanent items determined not to be subject to these requirements, and are subject to normal management and design controls.

Both documents reflect conclusions of Determination of Importance Evaluations (see Section 2.3.2); the Q-List also contains items originally placed thereon by direct inclusion using a conservative assumed basis. Items on the Q-List by direct inclusion require documented analysis to warrant their removal. The YMP evaluates recommended changes to the Q-List, based on a procedural review and an Assessment Team consisting of representatives from various Project participants.

No changes were made to the Q-List during this reporting period. Revision 3, originally forecast to be completed in FY 1994, was delayed to include proposed changes as a result of the Determination of Importance Evaluation associated with the North Ramp excavation (i.e., Exploratory Studies Facility Package 2C). This Determination of Importance Evaluation resulted in the recommendation that the North Ramp be formally recognized as the assumed Waste Ramp on the Q-List.

No changes were made to the Management Control List during this reporting period. Current plans call for deletion of the Management Control List and incorporation of its information into an appendix to the Q-List.

Forecast: Revision 3 of the Q-List is in review and is expected to be approved in early FY 1995. The Technical Document Preparation Plan discussed in Progress Report #10 is currently in review to govern the maintenance of the Q-List. This plan will supersede Administrative Procedure-6.17Q, thus eliminating the Assessment Team as an in-line

functional entity, and completing the transition to the classification and grading process which has been in development for the past two years. This plan includes criteria for making changes to the Q-List, based on classification analyses, and is anticipated to be completed and implemented in early FY 1995. This plan is also expected to result in deletion of the Management Control List as a discrete document.

2.4 PROGRAM OUTREACH

The DOE communicates issues to the public in an effort to create a climate of understanding. According to provisions in the Nuclear Waste Policy Act, as amended, public involvement is an integral component of the site characterization process. The Nuclear Waste Policy Act, as amended, states, "State and public participation in the planning and development of repositories is essential in order to promote public confidence in the safety of disposal of such waste and spent fuel." To achieve public involvement, DOE manages a variety of public outreach programs, the development of public information products, a media relations program, stakeholder interactions programs, and supports policy development. This section discusses many of the activities DOE has accomplished in the past six months as part of an ongoing effort to achieve the directive set forth in the Nuclear Waste Policy Act, as amended.

One hundred twenty-four tours of Yucca Mountain, including six Public Open House tours, were conducted for approximately 3330 members of the public and other interested parties. The tours for special groups included the State of Nevada Technical Review Committee, Mitsubishi Nuclear Fuel, the Steering Panel for the Independent Management and Financial Review, the National Security Industrial Association, the Nevada Legislature's Committee on High-Level Radioactive Waste, Energy Resource Laboratories - Taiwan, the International Accelerator Transmutation of Waste Conference, the Office of the Nuclear Waste Negotiator, the DOE Office of Economic Impact and Diversity, and Congressional Staff members and utility representatives.

Numerous programmatic and technical workshops, presentations, and meetings were held in various Nevada communities to provide current information to the public regarding site characterization progress. The Project also coordinated and attended three Affected Units of Government Meetings and three National Stakeholder meetings, and held two Neighborhood Dialogues. A total audience of approximately 8000 people attended 133 speaking presentations during this period, which included seven technical presentations, 59 general Project overview presentations, and 67 educational presentations.

The Yucca Mountain Science Centers, located in Las Vegas, Beatty, and Pahrump, Nevada, received approximately 5100 visitors during this period. At the Science Centers, the Project presented six Yucca Mountain Speaker Series presentations, three Girl Scout geology workshops, one Cadet Girl Scout field trip; two Boy Scout workshops, four teacher workshops, two Discovery Days, a Native American Day, "Visions in Culture," and 21 energy and geology workshops for fifth graders. Project public information exhibits were staffed for 26 events, with approximately 8700 visitors.

The Project produced and distributed a variety of public information products, including a new work update video; three other videos, including a 15-minute video on the tunnel boring machine model as a training and orientation tape; and a photo exhibit supporting a tunnel boring machine presentation. Project staff provided logistic and communications support for the OCRWM Education Teleconference, including coordination at the Sample Management Facility for satellite transmission equipment, camera positions, file video, and interviews with Project scientists. Project staff also supported a live news feed from the Exploratory Studies Facility for KVBC-TV, Channel 3, Las Vegas. Project staff designed and coordinated construction of a portable outdoor display at the North Portal Pad, using photos, maps, and graphics to explain the purpose and operation of the tunnel boring machine, and coordinated development of an exhibit and publicity for the DOE Science and Technology Showcase, which included displays of past, present, and future contributions to developing new technologies by the DOE and its contractors. Project staff completed development of and opened to the public the new Exploratory Studies Facility exhibit at the Las Vegas Yucca Mountain Science Center.

In September the Project awarded a grant to the National Urban Coalition in the amount of $405,068.00 for the "Say Yes to a Youngster's Future" program, to be conducted in seven elementary schools in West Las Vegas, Nevada, in conjunction with two Family Learning Centers. The program will be implemented in Clark County Schools and through working with the African Americans for Energy Awareness.

CHAPTER 3 - SITE PROGRAMS

The site characterization effort for the Yucca Mountain, Nevada, site consists of a number of component programs. These programs, a reference to the section providing a summary of the progress during this reporting period, and a summary of the activity are as follows:

- Geohydrology (Section 3.1) - investigates surface and subsurface hydrology on both site and regional scales, with ground water flow system characterization and modeling for both the unsaturated zone and saturated zone (SCP Section 8.3.1.2).

- Geochemistry (Section 3.2) - investigates and models rock chemistry and mineralogy, ground water chemistry, and geochemical behavior of materials along potential radionuclide transport pathways (SCP Section 8.3.1.3).

- Rock Characteristics (Section 3.3) - characterizes and models rock stratigraphic and structural features and distributions within the site area, and integrates geophysical and drilling activities to obtain subsurface stratigraphic and structural data (SCP Section 8.3.1.4).

- Climate (Section 3.4) - analyzes paleoclimate, paleohydrology, and paleo-environment, and characterizes modern climate, future climate, and future hydrology (SCP Section 8.3.1.5).

- Erosion (Section 3.5) - characterizes modern and past erosion and evaluates the potential effects of future climate and tectonics on erosion (SCP Section 8.3.1.6).

- Postclosure Tectonics (Section 3.6) - characterizes tectonic features such as igneous activity and fault and fold deformation in the Yucca Mountain vicinity, with emphasis on volcanic activity, and analyzes the potential effects of tectonic processes on a potential repository and the site ground water system (SCP Section 8.3.1.8).

- Human Interference (Section 3.7) - evaluates the known and potential natural resources in the site area, and the potential for future human intrusion into the site area in search of such resources (SCP Section 8.3.1.9).

- Meteorology (Section 3.8) - characterizes the site and regional meteorological conditions of the Yucca Mountain vicinity (SCP Section 8.3.1.12).

- Offsite Installations and Operations (Section 3.9) - determines the presence, and potential impacts on the site area, of offsite industrial, transportation, and military installations and operations in the Yucca Mountain vicinity (SCP Section 8.3.1.13).

- Surface Characteristics (Section 3.10) - characterizes the topographic characteristics and properties of soil and rock in the site area (SCP Section 8.3.1.14).

- Thermal and Mechanical Rock Properties (Section 3.11) - determines rock thermal and mechanical properties from laboratory and in situ investigations and characterizes thermal and mechanical stress conditions at the site (SCP Section 8.3.1.15).

- Preclosure Hydrology (Section 3.12) - characterizes the potential for flooding and determines location of an adequate water supply for repository construction and operation and preclosure hydrologic conditions in the unsaturated zone at Yucca Mountain (SCP Section 8.3.1.16).

- Preclosure Tectonics (Section 3.13) - characterizes faults, seismicity and tectonic stress field, and evaluates the potential for faulting, ground motion, and volcanic activity in the site vicinity (SCP Section 8.3.1.17).

- Altered Zone Characterization (Section 3.14) - a new activity that was not addressed in the Site Characterization Plan, has been created to develop and validate techniques to analyze the performance of the natural system under potential changes that result from waste emplacement (SCP Section - N/A).

These programs are discussed in detail in the referenced sections. In these sections are many references to study plans. The status of the study plans is summarized in Appendix E. In conjunction with the new Program Approach, an effort was initiated during this reporting period to address a Site Characterization Plan/Study Plan work scope consolidation. This was discussed in the DOE-NRC Management Meeting held September 21, 1994, in Rockville, Maryland. This effort identified Site Characterization Plan sections for which study plans have not yet been written and evaluated whether there is a rationale why a study plan need not be developed. Such rationale could include: transfer and/or aggregate work scope into other study plans; and report work already completed in a participant report, DOE technical report or working paper; or other rationale. As indicated in the Management Meeting, the results of those evaluations, the explanations, and the resulting proposed action(s), are discussed in the Forecast section for each appropriate study.

For the reader's reference, a map showing surface features in the Yucca Mountain vicinity is included as Figure 3-1. Figure 3-2 shows the location of boreholes in the proposed repository area.

3.1 GEOHYDROLOGY (SCP SECTION 8.3.1.2)

3.1.1 Study 8.3.1.2.1.1 - Characterization of the Meteorology for Regional Hydrology

The objectives of this study are to characterize the area surrounding Yucca Mountain in terms of precipitation and its relationship to surface runoff, with particular emphasis on the Fortymile Wash drainage basin, and to provide input into the rainfall-runoff model development effort.

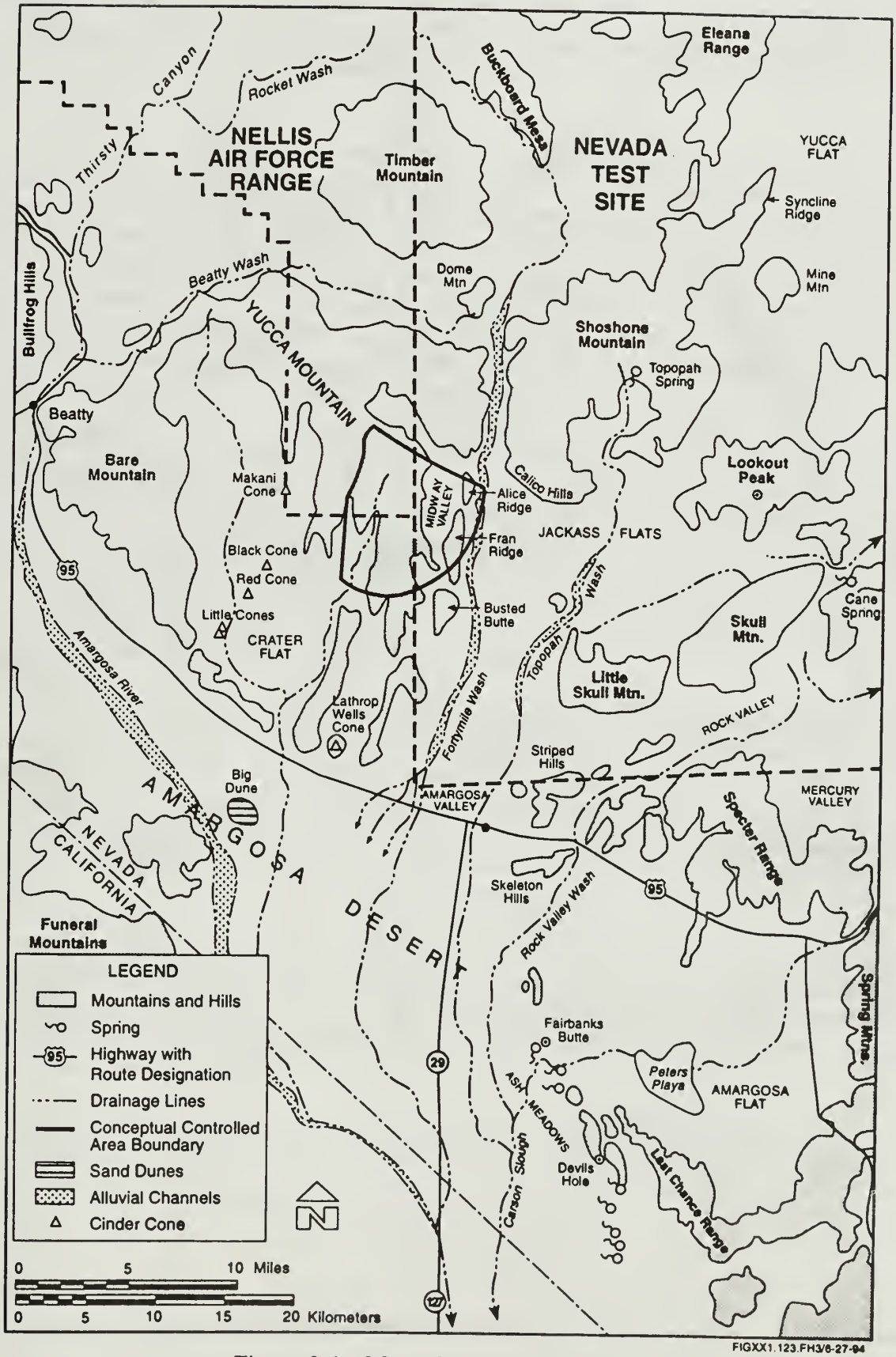


Figure 3-1. Map of Surface Features

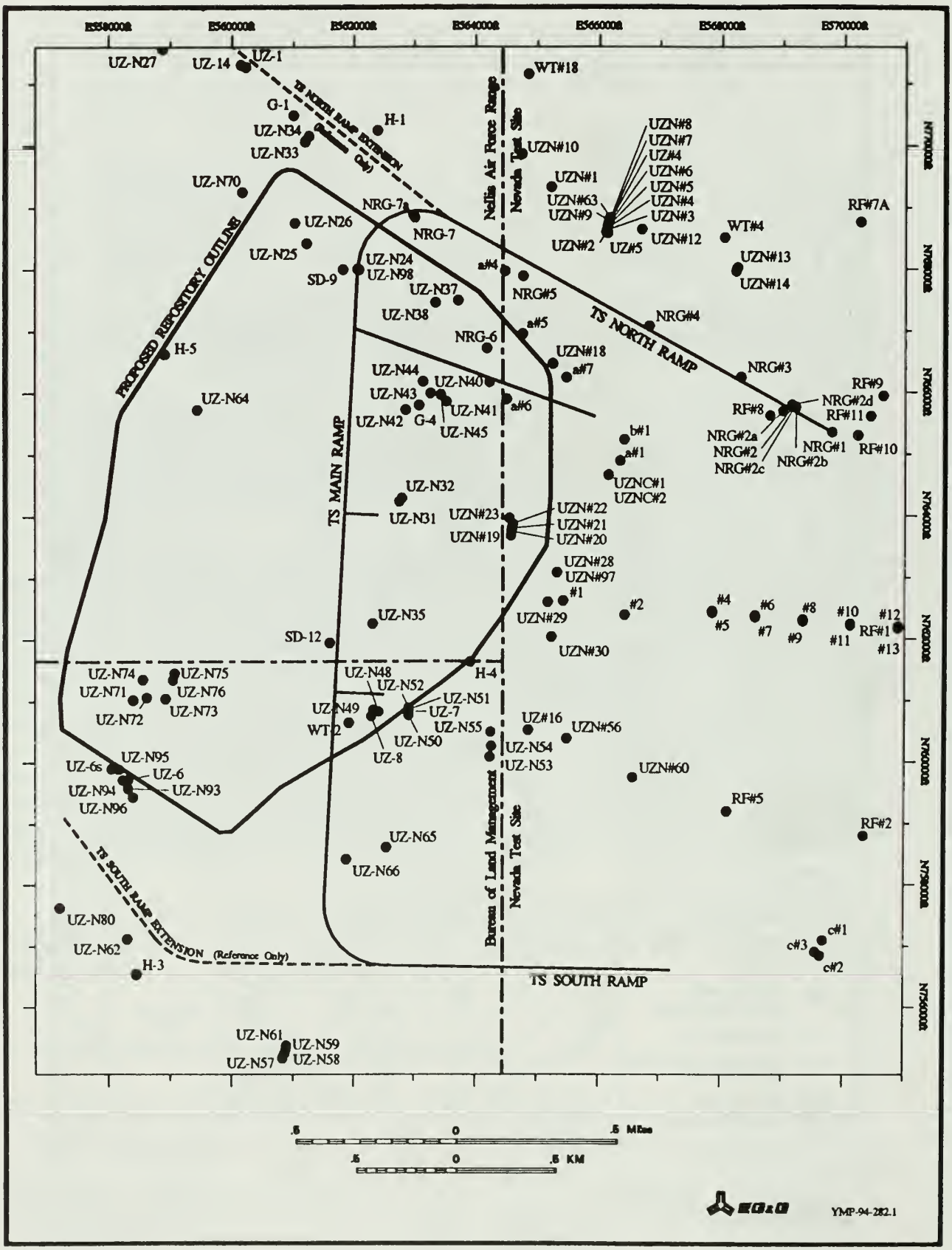


Figure 3-2. Map of Repository Area Boreholes

Activity 8.3.1.2.1.1.1 - Precipitation and meteorological monitoring. The objective of this activity is to provide site-specific information on storm precipitation at, and near, the network streamflow-measurement sites.

Precipitation and meteorological data are being collected to characterize the Yucca Mountain area and to determine their relationship to surface runoff and infiltration. Data collection continued during the reporting period. Site meteorological data from five weather stations plus four remote tipping-bucket rain gauge locations were downloaded, reviewed, and archived. Additional precipitation data were collected from the network of nonrecording (storage) rain gauges deployed on and around Yucca Mountain. The network now consists of 132 nonrecording gauges. During the reporting period, there were only seven precipitation events affecting Yucca Mountain and 1994 continued to be a below-normal year for area precipitation.

A geostatistical analyses of selected storm events at Yucca Mountain from 1991 to 1993 was conducted (Hevesi et al., 1994) and enhanced the understanding of precipitation distribution on the site scale on a storm-by-storm basis. Studies have shown that the presence of a gauge in the wind stream causes turbulence which reduces the catch and that pit gauges eliminate wind effects. The difference between summer and winter precipitation patterns was clearly evident and the analyses also found that snowfall measurements along the crest of Yucca Mountain were inaccurate. Measurement techniques will be altered to reduce the impact of this problem for next winter.

Collection and archival of satellite and lightning data continued. Synoptic weather charts were also received and analyzed daily. The daily synoptic weather patterns were cataloged according to five major weather types. Time-lapse video data of Yucca Mountain weather continued to be collected. A completely new laboratory technique for calibrating tipping-bucket precipitation gauges was developed. This technique is totally automated and saves a great deal of time. This technique is necessary to expand the tipping-bucket gauge network.

Forecast: The tipping-bucket rain gauge network will be expanded by at least 14 new gauges. Therefore, a rain gauge will be installed in a pit in USW WT-2 Wash along with a nonrecording gauge. Another pit on the crest of Yucca Mountain on or near the USW H-3 pad will house a tipping-bucket snow gauge. The catch from the pit gauges will be compared with the nearby gauges to measure the loss of precipitation due to wind effects.

A geostatistical analysis will be completed comparing up to 150 sites surrounding Yucca Mountain in Nevada and California with over a 30-year record to those at Yucca Mountain with only an 8-year record. Synoptic-scale, regional, and site-scale data will continue to be collected.

3.1.2 Study 8.3.1.2.1.2 - Characterization of Runoff and Streamflow

The objectives of this study are to collect basic data on surface-water runoff at, and peripherally to, Yucca Mountain and its hydrologic flow system; use the streamflow data to describe the runoff characteristics of the area and assess the response of runoff to precipitation; assess the potential for flood hazards and related fluvial-debris hazards to the Yucca Mountain Project; and provide basic data and interpretations of surface-water runoff to investigations that evaluate the amounts and processes of ground-water recharge at Yucca Mountain and surrounding areas.

Activity 8.3.1.2.1.2.1 - Surface-water runoff monitoring. The objectives of this activity are to develop needed basic data on the characteristics, magnitudes, frequencies, and timing of surface-water runoff to develop an understanding of the relationships between specific runoff events and the characteristics of the storms and associated precipitation; and to develop a streamflow data base adequate to provide the necessary calibration data for precipitation-runoff modeling efforts for the regional study area.

Streamflow and precipitation data collected at and near Yucca Mountain will be used as input to flood frequency analyses, infiltration modeling studies in the unsaturated zone and Fortymile Wash, and performance assessment. Monitoring activities continued at 14 continuous-recording stream gauges, 12 peak-flow sites, and 26 storage-type precipitation gauges. Three new continuously-recording stream gauges were installed in selected washes along the eastern slope of Yucca Mountain. A report summarizing these data (Kane et al., 1994) was published during the period. Work continued on processing streamflow and precipitation data collected during water year 1994.

Activity 8.3.1.2.1.2.2 - Transport of debris by severe runoff. The objective of this activity is to document, both quantitatively and qualitatively, the characteristics of debris transported by intense surface runoff.

No progress during the reporting period; this was an unfunded activity.

Forecast: Data collection and analyses from the streamflow-precipitation networks will continue. Two additional continuously-recording gauges will be installed at selected drainages along the eastern slope of Yucca Mountain to support the Unsaturated Zone Infiltration Study. Peak-flow gauges will also be installed to supplement data collected at these and other selected continuously-recording sites. Reports documenting runoff and precipitation data for Yucca Mountain and its vicinity for 1994 will be completed.

3.1.3 Study 8.3.1.2.1.3 - Characterization of the Regional Ground-Water Flow System

The objectives of this study are to further define the distribution of hydraulic properties of the regional ground-water flow system; and to use hydrologic, hydrochemical, and heat-flow data to determine the magnitude and direction of ground-water flow.

Activity 8.3.1.2.1.3.1 - Assessment of regional hydrologic data needs in the saturated zone. The objective of this activity is to prioritize data needs for use in the regional ground-water flow description.

An evaluation of this activity was made during the completion of the study plan in which a prioritization of project data needs was largely completed. It was determined that as new project data become available, data needs may change based on previously unrecognized hydrologic conditions. The current data uncertainty was used to prioritize data collection needs, as documented in the study plan.

Activity 8.3.1.2.1.3.2 - Regional potentiometric-level distribution and hydrogeologic framework studies. The objectives of this activity are to determine the potentiometric distribution within the regional ground-water flow system, and to characterize the hydrogeologic framework of the regional ground-water flow system to support reliable estimates of ground-water flow direction and magnitude within the saturated zone.

Various hydrologic test data from Drillhole USW G-2, which included tracejector and spinner surveys, geophysical logs, and hydrochemical sampling were reviewed and processed. Temperature logs from Borehole USW G-2 were analyzed and processed to obtain estimates of vertical ground water flux. Temperature logs from USW G-2 and other holes in the area reveal a complex thermal regime significantly influenced by vertical fluid movement. Historical water-level data from USW G-2 also were analyzed and showed a substantial drop (12 m) in water levels from the time of initial measuring to the present. The decline in water levels may be the result of drainage from a perched or semi-perched water body in or above the Calico Hills unit, through the borehole, down to a receptive fracture or fracture zone. USW G-2 represents an important water level monitoring point on Yucca Mountain in that it is one of two points on the upgradient side of a feature referred to as the "large hydraulic gradient" area. This analysis also included a review of geophysical logging done in USW G-2. Tracejector survey results from USW G-2 from 1981 were processed into graphical form. Spinner and tracejector surveys completed during fluid injection into USW G-2 showed transmissive zones within the Calico Hills Formation and Prow Pass Member of the Crater Flat Tuff. If the water level measured in USW G-2 is representative of a perched or semi-perched system that is coupled via the borehole to the regional saturated zone, the significance of the supposed "large hydraulic gradient" diminishes considerably.

Alternatively, the presence of transmissive zones in the Calico Hills unit and apparently not below (based on temperature logs) may be the result of thermal alteration in the basement rocks, which likely were closer to caldera heat sources. This pattern of alteration could have produced a series of stepped low-permeability surfaces to account for the large hydraulic gradient. This information and analyses will be documented following hydraulic testing of USW G-2.

Activity 8.3.1.2.1.3.3 - Fortymile Wash recharge study. The objective of this study is to determine to what extent (quantitatively, if feasible) that Fortymile Wash has been a source of recharge to the saturated zone under present and past conditions.

Soil-moisture and depth-to-water measurements were made in upper Fortymile Wash on a regular basis. Ground water levels and unsaturated-zone soil moisture continued to decline following a period of recharge in January-March, 1993. Precipitation, streamflow, unsaturated zone, and saturated zone data for Water Year 1993-94 were compiled for inclusion in a USGS Report. Regional surface water data were compiled from several long-term USGS gauging stations in the southwestern United States to determine if El Niño effects could be found and correlated to Yucca Mountain area surface water gauges. Surface water data from Fortymile Wash during 1984 were analyzed for transmission losses (infiltration of streamflow into streambed gravel). The abstract documenting and summarizing the data analyses (Savard and Beck, in prep.) was submitted to the American Geophysical Union for presentation at the 1994 Fall Meeting. A second report (Savard, in prep.) presents and documents meteorological, surface water, unsaturated zone, and saturated zone data.

Activity 8.3.1.2.1.3.4 - Evapotranspiration studies. The objective of this activity is to improve estimates of ground-water discharge by evapotranspiration in the Amargosa Desert to provide boundary-condition data for regional ground-water flow models.

Tests were performed on a Bowen ratio station on Franklin Lake Playa. The station is being tested for its suitability for yielding long-term continuous estimates of evapotranspiration at a central site on the playa. The tests indicated problems with measuring low relative humidities (less than 15 percent) using a cooled mirror device because of the formation of persistent ice during the measurement. Long-term estimates of evapotranspiration will provide estimates of ground water discharge to be used in flow models.

Forecast: Hydraulic and hydrochemical testing of the upper saturated interval in Borehole USW G-2 will be conducted. Monitoring of water-levels, soil moisture, and precipitation will continue in Fortymile Wash. An infiltration test will be conducted using a three-foot ring infiltrometer.

3.1.4 Study 8.3.1.2.1.4 - Regional Hydrologic System Synthesis and Modeling

The objectives of this study are to synthesize the available data into a model and make a qualitative analysis of how the system is functioning, and to represent quantitative observations of hydrogeologic data pertaining to the ground-water flow system in a comprehensive numerical model of ground-water flow.

Activity 8.3.1.2.1.4.1 - Conceptualization of regional hydrologic flow models. The objectives of this activity are to synthesize available data into a conceptual model that incorporates alternative hypotheses and/or existing hypotheses, and to make a qualitative analysis of how the regional and subregional ground-water flow systems function.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.2.1.4.2 - Subregional two-dimensional areal hydrologic modeling. The objective of this activity is to improve estimates of regional ground-water flow by updating an existing two-dimensional, subregional, parameter-estimation model through the incorporation of additional hydrogeologic data.

A method was developed to allow quicker and more complete evaluation of how well ground water modeling output from the MODular Finite Element (MODFE) model (Czarnecki, 1994) reproduces the ground water system under transit conditions. UNIX script files were finalized for developing vector and contour plots of numerical-model simulations for each printed time step. Results of this work were presented at the USGS National Computer Technology Meeting in New Orleans in March 1994.

Activity 8.3.1.2.1.4.3 - Subregional two-dimensional cross-sectional hydrologic modeling. The objectives of this activity are to estimate the ground-water flow direction and magnitude along a potential flow path through the repository block to the accessible environment, and extending into the region, to help test the assumption of horizontal flow.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.2.1.4.4 - Regional three-dimensional hydrologic modeling. The objective of this activity is to construct a three-dimensional model of the regional ground-water flow system of Yucca Mountain and vicinity.

The three-dimensional hydrogeologic framework model of the Death Valley regional ground-water flow system developed for regional numerical modeling efforts was updated to remove model inconsistencies and improve gridded structural surfaces. The model, developed using Stratamodel's Stratigraphic Geocellular Modeling System, also was modified to represent a more detailed model of the Amargosa Valley region for use in planning site-scale modeling. The regional model will assist in defining site-scale model boundaries.

Several reports discussing and documenting components of this effort were in preparation during this period. Faunt et al. (in prep.) will provide a description of the regional hydrostratigraphy used in construction of the hydrogeologic framework model. D'Agnese et al. (in prep.) contains a discussion of the data used to construct the hydrostratigraphic map and hydrogeologic framework model. A second report by Faunt (in prep.) will describe the role of faults and other structural discontinuities on regional ground water flow.

Basic hydrologic analysis of the regional flow system was completed. Water balance estimates and conceptualization of ground water flow was formalized. D'Agnese (in prep.) will describe and document the methods used in construction of the regional potentiometric-surface map used in regional modeling and subregional boundaries to the flow system.

Preliminary numerical ground water flow simulations of a 190-row, 155-column, and 4-layer model were continued. Initial runs showed reasonable agreement with observed conditions, but improvements were needed. As a result, an improved model design was

implemented to simulate the regional flow system in three layers. Plans were developed to utilize both MODFLOW and MODFLOWP in the calibration of this improved model. Meanwhile a calibration protocol and sensitivity analysis plan was revised for the model.

Forecast: The regional hydrogeologic framework model will be improved and modified. The numerical model will be calibrated utilizing both MODFLOW and MODFLOWP codes. Reports documenting data used in the regional modeling activity will be developed. Also, regional modeling efforts will closely interact with site-scale modeling efforts to suggest potential boundary conditions and impacts to the site flow system. Construction of finite-element model simulations of the revised subregional model domain with dense mesh refinement at Yucca Mountain will continue. Interfaces with ARC INFO to build three-dimensional layers in the three-dimensional version of the USGS MODFE model will be researched.

3.1.5 Study 8.3.1.2.2.1 - Characterization of Unsaturated-Zone Infiltration

The objective of this study is to determine present-day net-infiltration rates (fluxes) occurring under natural precipitation events, range of expected net infiltration rates and pathways under possible future wetter climate conditions, and hydrologic properties of surficial materials.

Activity 8.3.1.2.2.1.1 - Characterization of hydrologic properties of surficial materials. The objective of this activity is to characterize the infiltration-related hydrologic properties and conditions of the surficial soils and rocks covering Yucca Mountain.

The effects of annular washout zones around boreholes on measurements from neutron-neutron geophysical tools and neutron moisture meters was investigated. It is necessary to understand these effects to accurately interpret geophysical logs for determination of density, porosity, and water content. These washout zones are likely an artifact of the drilling process and appear to exist to various extent in many of the unsaturated zone boreholes at Yucca Mountain. While quantitative interpretations of the logs have not been obtained, the qualitative effects are clear. The casing at UE-25 UZN#85 was pulled to verify predicted washout zones around the casing. The washout zones were predicted in the cased borehole from gamma-gamma logs, neutron moisture meter logs during a ponded infiltration experiment, and numerical models of the ponded infiltration experiment. Both caliper logs and video logs confirmed the predicted washouts. Work continues to use gamma-gamma logs and neutron-neutron logs to quantitatively detect and compensate for washouts in cased boreholes.

The effort to develop techniques for using standard wireline geophysical tools in unsaturated boreholes continued. Boreholes in Pagany Wash (UE-25 UZ #1, #3, #4, #5, #6, #7, #8, #9, #10, #63), WT-2 Wash (UE-25 UZN #54 and #55), Yucca Crest (USW UZ-N27), Jackass Flats (UE-25 UZN#39), H-4 Wash (USW UZ-N35) and Drill Hole Wash (USW NRG-6) were logged with gamma-gamma and neutron-neutron geophysical tools to determine wet and dry density, porosity, and moisture content. These logs are also being

used to develop density and water content calibrations and data transfer techniques, to determine depth to bedrock, and to determine porosity profiles and washout zones.

The effects of rocks fragments (>2 mm diameter) on the saturated hydraulic conductivity and the water retention properties of the skeletal soils at Yucca Mountain was measured. Fragments less than 9 mm contributed to the hydraulic properties of the fine soil material. The results of this study will be presented at the Soil Science Society of America Meeting in November 1994 (Guertal et al., in prep.). A study to determine the effects of various pre-treatments on rock fragments prior to particle size analysis indicated that washing and soaking the rock fragments overnight in 50 g/L sodium meta-phosphate solution prior to particle size analysis was adequate to remove fine material from the rock fragments.

Characterization of the hydraulic and physical properties of the unconsolidated surficial material continued. Measurements were concentrated on characterizing the hydrologic properties of the surficial units identified in Lundstrom et al. (in prep.). Measurements of field bulk density, rock and sand fraction sieving, particle size analysis, $CaCO_3$, pH, porosity, particle density, water retention, and saturated hydraulic conductivity were completed on surface and pit samples from Pagany Wash, Yucca Crest, WT-2 Wash, Midway Valley, Coyote Wash, Drill Hole Wash, Dune Wash, Castle Point, and Busted Butte.

Activity 8.3.1.2.2.1.2 - Evaluation of natural infiltration. The objective of this activity is to characterize present-day infiltration processes and net-infiltration rates in the surficial soils and rocks covering Yucca Mountain.

Water content profiles from 97 unsaturated zone neutron-access boreholes were measured at monthly intervals by geophysical logging using neutron probes. Preliminary calibration equations for 10 neutron moisture meters were completed. A preliminary map of the spatial distribution of the near-surface matrix vertical flux identified areas of relatively high net infiltration rates (approximately 13 mm/yr) over portions of Drill Hole Wash, Pagany Wash, and locations where the nonwelded Paintbrush Tuff crops out or is close enough to the surface to be influenced by shallow infiltration during the winter season and/or episodic runoff events. In contrast, vertical matrix flux through the welded Tiva Canyon Tuff overlying most of the potential repository was determined to be 0.02 mm/yr using the 8-year record of measured water-content profiles and assuming a unit gradient beneath the zone of seasonal influences (precipitation and evapotranspiration). These results are preliminary and are in the process of being verified using numerical modeling and field tests. In addition, the results are incomplete until the influence of fracture flow in the near surface has been characterized, potential fast pathways of net infiltration (fault zones) have been evaluated, and water potential gradients below the zone of seasonal influences have been measured.

A conceptual model of shallow infiltration was defined using an analysis of relative changes in water-content profiles from 1990 through 1993 for 34 boreholes in Pagany Wash and WT-2 Wash. Water content changes with depth and time were compared subjectively based on four conceptual infiltration zones (ridgetops, sideslopes, terraces, and active channels), and the seasonal variability of precipitation, potential evapotranspiration, and geology. The analysis indicated that the potential for net infiltration is higher during the

winter season, at locations where topography and surficial materials are likely to cause a concentration of runoff (particularly over fractures or more permeable bedrock), and where a shallow alluvial cover is conducive to maintaining saturated or near saturated conditions over fractured or more permeable bedrock at a depth sufficient to mitigate evapotranspiration between precipitation events. This analysis is continuing using the record of water content changes obtained at all 97 borehole sites.

The development, calibration, and verification of one-dimensional numerical models of shallow infiltration and evapotranspiration using measurements of precipitation, potential evapotranspiration, and water-content profiles continued. Analysis of evapotranspiration continued using measurements from a class A evaporation pan in Jackass Flats, a Bowen ratio station in Pagany Wash, a network of time domain reflectometry probes in Pagany Wash, and five full Penman weather stations. Model verification was continued at additional borehole sites. Results indicated a decrease in the potential for net infiltration at locations with more than 2 to 3 m of alluvial cover (in the absence of runoff) due to the combination of a high near-surface storage capacity for alluvium and summer season evapotranspiration. However, the influence of episodic runoff events on long-term net infiltration must be characterized using measured runoff events, ponding experiments, and stochastic precipitation models. A stochastic precipitation model is being developed using a regional network of approximately 150 stations.

Activity 8.3.1.2.2.1.3 - Evaluation of artificial infiltration. The objective of this activity is to characterize the possible range and spatial variability of infiltration in the upper 5 m at Yucca Mountain.

One-dimensional and two-dimensional radial flow numerical models were used to evaluate the results for a 60.5-hour ponded-infiltration experiment conducted at UE-25 UZN#85. Specific results of this experiment were prepared for presentation at the Soil Science Society of America Meeting in November 1994 (Hudson et al., in prep.).

Results of an evaluation of existing instruments and methods used to measure infiltration capacities and their appropriateness for determining hydrologic properties at Yucca Mountain are documented in Hofmann et al. (in prep.). The report also presents preliminary infiltration data, estimated measurements of saturated hydraulic conductivity and sorptivity, and describes the methods used to collect the data. The cumulative infiltration data were fit using the two-term Philip equation from which saturated hydraulic conductivity and sorptivity values were derived. The saturated hydraulic conductivity values at selected locations differed by an order of magnitude. Sorptivity values differed by more than 100 percent between the various locations. Differences in the infiltration rates were attributed to differences in measured physical characteristics and differences in initial water contents of the soils at the selected locations.

Surface infiltration rates and sorptivity values for each of the infiltration runs using the double ring infiltrometer at two locations near UE-25 UZN#7 were determined. Bulk density and sidewall samples were collected at each site. These samples are used to determine a number of physical and hydrologic characteristics, which are an important part of site scale

unsaturated-zone modeling. Inverse modeling techniques and TOUGH model simulations were used to model the double-ring infiltrometer runs.

Forecast: The development of hydrologic properties for the preliminary Surficial Materials Maps will be continued. Both laboratory, field, and borehole geophysical measurements of the hydraulic and physical properties will be used to characterize surficial materials at Yucca Mountain. These properties will be incorporated in a surficial materials properties map and used to develop an infiltration flux map. Fracture and fault hydrologic properties will be measured and used to develop a fast-pathways infiltration map.

A study site in Split Wash for the detailed analysis of evapotranspiration will incorporate instrumentation for the continuous monitoring of near-surface water content, soil temperature, and water potential in conjunction with estimates of evaporation and potential evaporation using a Bowen ratio station, a Penman weather station, and continuous measurements of vertical water-content changes and water potentials using two fully instrumented boreholes.

The regional meteorology data base will be used to develop a stochastic model of precipitation at Yucca Mountain as input to infiltration models for predicting the response of natural infiltration to climatic variability and potential long-term climatic change, and also for predicting the areal distribution of infiltration as a dynamic component of the catchments on Yucca Mountain. The precipitation model will consist of a numerical characterization of both the spatial and temporal variability of variables such as precipitation amount, intensity, duration, and timing.

The neutron logging data base, consisting of the measured volumetric water-content profiles at more than 90 boreholes, will continue to be used for the development and calibration of infiltration models that include measured precipitation and potential evapotranspiration as input. An emphasis will be placed on analyzing and modeling the processes of infiltration and evapotranspiration at boreholes located in fractured bedrock at various topographic locations and having various thicknesses of alluvium cover.

Summer evaporation rates will be determined over large areas using a Monin-Obukov similarity method on vertical transects derived from two-dimensional vertical lidar scans. Various evaporative models in common use will be evaluated for use in modeling local evaporative flux; the goal being a model which gives reliable results using data currently being measured at the site.

3.1.6 Study 8.3.1.2.2.2 - Water Movement Test

The objective of this study is to obtain information from isotopic measurements of soil, tuff, and water samples collected to help quantify the amount of percolation from precipitation into the unsaturated zone at Yucca Mountain.

Activity 8.3.1.2.2.2.1 - Chloride and chlorine-36 measurements of percolation at Yucca Mountain. The objective of this activity is to help quantify the amount of percolation from precipitation into the unsaturated zone at Yucca Mountain. The data will be used as part of the input to characterize the movement of water through the unsaturated zone at Yucca Mountain.

All laboratory operations for this study were consolidated and moved to Los Alamos. An additional staff researcher was hired to streamline sample processing and to refine the models used to estimate infiltration rates. A data base to track various analyses associated with the 700 samples on hand at Los Alamos was constructed.

Project scientists collected several vertical profiles from the soil and fractured rock face exposed at the UE-25 NRG#5 drill pad to evaluate the role of the soil cover and fractures in transmitting infiltrating water into the Tiva Canyon welded (TCw) unit. All 19 soil samples analyzed had chlorine-36 values considerably above natural background, indicating the possible presence of chlorine-36 from global atmospheric weapons testing fallout and hence fairly recent water at all depths. (Note: none of the fracture samples have yet been analyzed.) This information will be used by USGS in its preparation of a site-scale map delineating infiltration zones, which in turn will be used to define the upper boundary condition of the site-scale hydrologic model.

Project scientists continued to evaluate elevated chlorine-36 results throughout the profile for Borehole USW UZ-N55. A hypothesis being evaluated is that these anomalous results are a consequence of contamination of the drilling equipment from its previous use, and not an indication of deep penetration of recent water containing elevated chlorine-36 at this location. As one test of this hypothesis, soil samples were collected from Test Cell C where the drill rig had previously been used. Six of the nine samples had ratios that were nearly three orders of magnitude above natural background, and even one order of magnitude above the peak signal for global fallout of chlorine-36 from nuclear weapons testing. This elevated signal can be attributed to neutron activation of soil chloride during nuclear reactor engine tests conducted at this site between 1959 and 1969, and it is viewed as proof-of-principle for the feasibility of contamination from this source.

A hydrologic issue of pressing concern is the origin and stability of perched water underlying Yucca Mountain. Project scientists measured the chlorine-36 signal in a perched water sample from USW NRG-7/7a and found it to be at meteoric background, with no indication of an elevated component. This finding is in contrast with previous results from perched water samples from USW UZ-1 and USW UZ-14, both of which indicated an elevated component (small in the case of USW UZ-14). The variability in signal suggests mixing of water, either from more than one source (e.g., water accumulating via natural infiltration processes mixing with water taken from UE-25 J#13 with that used during drilling of USW G-1), or from more than one pathway (e.g., fast transport of recent water with a high chlorine-36 content, mixing with older water infiltrating slowly). In any case, the average residence time of water in this perched body is no more than 50,000 years because the chlorine-36 signal has not decayed below its initial pre-1952 value.

Estimates of average ground water residence time have been obtained in this study by leaching rock cuttings to extract chloride for analysis of chlorine-36, a naturally-occurring radionuclide which is carried into the subsurface by percolating water. A key question is the extent to which the isotopic composition of leached chloride is representative of pore water chloride. To address this question, YMP scientists measured the isotopic composition of pore water extracted directly from UE-25 UZ#16 drill core and found it to be statistically indistinguishable from that obtaining by leaching the cuttings from the same unit. The pore-water result indicates an upper limit for the average residence time on the order of 200,000 years; however, a lower limit for the water age is not possible to establish at this time. In a related activity, Project scientists obtained chlorine-36 analyses for 15 ground water samples collected from springs and shallow wells in the Amargosa Valley. All samples had chlorine-36 concentrations that were at or below meteoric background. These data will be used to estimate upper limits for ground water ages at these locations. A paper is in preparation describing infiltration processes at Yucca Mountain inferred from chlorine-36 distributions (Fabryka-Martin, in prep.).

Project scientists obtained an AS3500 Bioinert Autosampler, which made it possible to collect reliable data on chloride/bromide ratios for a suite of 76 surface soil samples. This ratio is a key parameter used to correct the water residence time estimates for deep rock samples based on chlorine-36 measurements. This sample analysis will assess the variability in the meteoric component of halides entering the unsaturated zone. The results will be described in Fabryka-Martin (in prep.).

Modeling studies were under way to evaluate possible moisture migration pathways that are consistent with the observed chlorine-36 distributions. An abstract was published describing this work (Fabryka-Martin et al., 1994).

Forecast: Near-surface samples will be collected and analyzed to estimate present-day shallow infiltration rates, based on the distribution of bomb-pulse chlorine-36. Determine the depth to which bomb pulse chlorine-36 has penetrated, and correlate such distribution with lithology and structural features. The average residence time of infiltrating water as a function of depth will be estimated, based on the extent of decay of natural background chlorine-36. Efforts with site-characterization process modelers and performance assessment modelers to use the chlorine-36 results to validate hydrologic and solute transport model scenarios will be coordinated.

3.1.7 Study 8.3.1.2.2.3 - Characterization of Percolation in the Unsaturated Zone–Surface-Based Study

The objectives of this study are to determine the present in situ hydrologic properties of the unsaturated zone hydrogeologic units and structural features; to determine the present vertical and lateral variation of percolation flux through the hydrogeologic units and structural features; to investigate the relationships between present flux and past climatic conditions; and to determine the effective hydraulic conductivity, storage properties, and transport properties as functions of moisture content or potential.

Activity 8.3.1.2.2.3.1. - Matrix hydrologic properties testing. The objectives of this activity are to conduct laboratory measurements of rock-matrix hydrologic properties on borehole and Exploratory Studies Facility samples from geohydrologic units in the unsaturated zone, and the application of statistical and geostatistical methods to characterize spatial distribution of hydrologic properties within the unsaturated zone.

A data set of physical and hydrologic properties of rock outcrop samples at Yucca Mountain incorporating over 800 samples collected from eight surface outcrop transects was compiled. These transects were located to represent the vertical stratigraphy and spatial variability of the volcanic tuffs which are present in nonwelded and welded layers in the major flow units. Horizontal variability was examined for several lithologic zones by conducting horizontal transects. Physical and hydrologic properties were measured and descriptive statistics were calculated. Estimates of properties for hydrogeologic units were made as a simplification for flow modeling and for use in compilation of moisture-retention curve-fit parameters for predicting unsaturated flow. This work is documented in a report by Flint et al. (in prep.).

These analyses showed that there are several lithologic transitions throughout the unsaturated zone that have rapid property changes with depth. The transitions are (1) the upper cliff zone of the Tiva Canyon Member, which is exposed in most ridgetop locations at Yucca Mountain and grades from a high porosity to a low porosity rapidly with depth, (2) the nonwelded base of the Tiva Canyon Member (shardy base) that grades from a low porosity to a high porosity with depth, and (3) the transition between the nonwelded Topopah Spring Member and the highly vitric caprock, which changes from high porosity (30-40 percent) to very low porosity (2-4 percent) over several centimeters. These transitions represent stratigraphic units that may form flow barriers, suggesting that many thin layers may be needed to adequately model water flow. Predicting the likely occurrence of lateral diversions of flow also may require two-dimensional and three-dimensional models in several locations. It appears that porosity may be a reasonable surrogate with which to estimate saturated hydraulic conductivity and, in some cases, van Genuchten moisture-retention parameters for welded and nonwelded tuffs on the basis of these analyses.

Another study was finalized that analyzed a two-dimensional transect where 26 vertical transects, 5 to 10 m in length, were conducted over a 1,100-m distance along the partially welded to nonwelded shardy base unit of the Tiva Canyon Member exposed in Solitario Canyon using transect samples. Over 300 samples were collected and it was determined there was little horizontal variability. Furthermore, deterministic processes of volcanic deposition and cooling provided properties that were very predictable with depth. Models were fit to all the data and it was found that porosity and saturated hydraulic conductivity could be predicted in boreholes and transects over the site if the stratigraphic elevation within the shardy base unit was known. As one moved north closer to the source of the tuffs, the predictions were less successful. The data are presented and discussed by Rautman et al. (in prep.) and the analyses are published (Istok et al., 1994). An additional study is almost completed that duplicated the study on the overlying welded tuff, the columnar zone of the Tiva Canyon Member.

Activity 8.3.1.2.2.3.2 - Site vertical borehole studies. The objectives of this activity are to define the distribution of water content and water potential within the unsaturated zone; and to determine in situ bulk-permeability and bulk-hydraulic properties (i.e., combined fracture and matrix of the media within the unsaturated zone).

Drilling

Drilling of USW UZ-14 was completed in May 1994 to a total depth of 680 m. Water inflow into this borehole occurred from a single fracture in the Bullfrog Member of the Crater Flat Tuff located near the bottom of the borehole. By mid September, the water level in USW UZ-14 had risen 105 m to 572 m below ground surface (elevation approximately 779 m above mean sea level). After almost four months of monitoring, the water level in this borehole was still rising, albeit at a slow rate. The water-level recovery history in this borehole indicates extremely low matrix permeability associated with the Crater Flat Tuffs at this location and the lack of an effective interconnected fracture network at depth. During drilling of this borehole, perched water was encountered at a higher elevation in the section, above the basal vitrophyre of the Topopah Spring Member of the Paintbrush Tuff. Many fractures containing free water also were encountered both above and below the perched water body. Several of these fractures, especially those beneath the basal vitrophyre, drained water into the borehole during drilling. The matrix surrounding these "free-water" fractures, did not appear (at least visually) to be saturated, suggesting that lateral flow is probably responsible for the accumulation of perched water above the basal vitrophyre at USW UZ-14, and below the basal vitrophyre at USW SD-9 and USW NRG-7/7a (two nearby boreholes situated along the alignment of the North Ramp and main drift of the Exploratory Studies Facility). The setting and proximity of all these boreholes suggests that south to southeasterly lateral flow is a more likely mechanism than vertical percolation for explaining the accumulation of perched water in the area of the North Ramp of the Exploratory Studies Facility.

Vertical Seismic Profiling

The vertical seismic-profiling survey is designed to complement the drilling, air-permeability testing, and borehole monitoring programs by defining the extent of both large and small scale features that are not readily discernible from widely-spaced isolated boreholes. The vertical seismic profiling program planned for UE-25 UZ#16 will investigate a substantial portion of the southern half of the repository block and immediate surroundings. This survey will extend 1830 m west and 760 m east of UE-25 UZ#16, tracing the equivalent of an east-west cross section from the crest of Yucca Mountain, across the Ghost Dance fault, the imbricate structure on the eastern flank of Yucca Mountain, and the northwest-trending Sundance fault. Vertical seismic profiling uses seismic reflections and first arrivals to produce images of the subsurface geology that includes formation boundaries, other lithologic boundaries, faults, and fracture zones in order to determine the presence, location, depth, attitude, and spatial extent of these features. Several hundred seismic source locations will be energized with three-component sources, and 96 three-component geophones will be grouted into the borehole. During the period, final preparations were made to instrument the

UE-25 UZ#16 borehole with geophones, and to make final plans and preparations for the massive data acquisition and processing effort.

The processing system was extensively tested during the period with data from a preliminary vertical seismic-profiling ("zero offset" and "walkaway") survey conducted at the UE-25 UZ#16 borehole in August 1993. Four important results were obtained from this preliminary study: (1) strong coherent reflections are present on the vertical seismic profiling recordings, (2) these coherent reflections were greatly enhanced by proper computer rotation of the three component data, (3) preliminary imaging of reflections suggests some geologic horizons may have a westerly dip, and (4) the seismic computer-processing system is viable and will manipulate and process the enormous quantity of seismic data anticipated from the production survey.

Borehole Instrumentation and Monitoring

Plans to instrument borehole USW UZ-14 were put on hold as a result of the flux of perched water that continues to drain into the hole. USW SD-9 was not instrumented due to the perched water zone that was encountered; sensor calibrations for this hole that were in progress will be used in other boreholes planned for instrumentation in FY 1995.

Two high priority boreholes, USW NRG-6 and USW NRG-7/7a, will be instrumented in early FY 1995 with eight monitoring stations to measure pneumatic pressure, temperature, and water potential. The primary purpose of instrumenting these two boreholes is to assess the effects of tunnel construction on ambient, underground pneumatic pressures along the alignment of the North Ramp of the Exploratory Studies Facility. A nearly one-year data record will be acquired from these two boreholes before the tunnel boring machine reaches their respective locations. Stemming plans are in the final stages of preparation, and all instruments, sensors, equipment, shelters, etc were procured.

A grout-pump study was conducted at UE-25 UZ#16 to evaluate different sizes of tremmie pipes, grout emplacement and tagging techniques, and pipe maintenance schemes to ensure that the tremmie pipe will remain open during stemming operations. Results of these tests indicate that a single tremmie pipe can be used to emplace both wet and dry materials, and that the pipe maintenance techniques employed will be adequate to prevent grout from caking and sealing the pipe.

Hydrologic Data Acquisition System

The automated data collection system for borehole monitoring was tested and simplified. A version of the program was developed for use on a single computer instead of a network, and a modification was made to allow the keyed entry system to be read to the insulated instrument shelter, and for automatic data transfer using radio modems, was developed and integrated into this version. This version also includes automatic updating of control parameters using the radio modems. A script (batch file) process was developed for the IDISPLAY program which is used to display and evaluate the sensor data. Additional

programs were developed for use in testing sensors for proper operation before use in a borehole.

Evaluation of data from the Hydrologic Research Facility boreholes continued throughout the reporting period. Sensors in these boreholes have been in operation for 35 months and continue to provide reliable data. Initial data from the recalibration of sensors in the second borehole indicate minimal drift after two years of operation.

Surfaced-based Air-Permeability Testing

Permeability controls the flow of gas and liquids in Yucca Mountain. Surface-based air-permeability testing is being conducted to quantify the permeability of Yucca Mountain tuffs and testing in Borehole UE-25 UZ#16 was completed during this period. UE-25 UZ#16 was drilled with the LM-300 and is about 31 cm in diameter. The LM-300 dual wall reverse circulation system resulted in minimal skin effects and therefore analysis of test results is simplified. Permeability values range from 10^{-16} m^2 in the Calico Hills to 10^{-10} m^2 in the Tiva Canyon. The large range of permeability values suggests that gas and liquid flow systems in Yucca Mountain may be more complicated than the present flow models suggest. Statistical analysis showed no direct correlation between fracture density and permeability. Because air-permeability is a function of matric potential, tests were conducted at several different flow rates to evaluate if testing was altering the moisture content of the rock. At shallower test depths, there were no indications of altered water content; however, at greater depths, where the moisture content is greater, testing indicated that the air-injection was forcing water from the rock and thereby increasing the permeability.

Air-permeability testing was also completed in USW NRG-7/7a, which was drilled to 92.1 m with an 18.8-cm drill bit and then to 461.3 m with a 14-cm drill bit. A new 12.7 cm and 20.3 cm packer system was constructed to test USW NRG-7/7a and the initial analysis of USW NRG-7/7a air-permeability data showed that skin effects are much greater than in UE-25 UZ#16. Skin effects presumably resulted from the NRG holes being drilled using standard dry drilling technology, whereas UE-25 UZ#16 was drilled with the LM-300. The wellbore skin problem introduced some uncertainty, required longer time periods for conducting each test, and complicated the permeability analysis.

Activity 8.3.1.2.2.3.3 - Solitario Canyon horizontal borehole study. The objectives of this activity are to determine the extent of fracturing, brecciation, and gouge development in the Solitario Canyon fault zone; to evaluate the effects of fault zone on ground-water movement in the unsaturated zone; and to identify additional fault-zone-related data needs.

No progress during the reporting period; this was an out-year activity.

Forecast: As boreholes are drilled and samples processed over the next year, the extensive data set of matrix hydrologic properties will be used to delineate the hydrogeologic units over the entire site. Means and standard deviations for physical and hydrologic properties modeling parameters, as well as spatial distribution of the properties will be

provided for the hydrogeologic units. This will be assisted by the planned effort to evaluate unsaturated flow measurements and estimation methodologies.

Sensors for boreholes to be instrumented in 1995 will be calibrated. Three additional instrument shelters will be constructed. Boreholes USW NRG-6, USW NRG-7/7a, USW SD-12, USW UZ-7, UE-25 UZ#4, and UE-25 UZ#5 will be instrumented and UE-25 UZ#16 will be instrumented for vertical seismic profiling. A report documenting the hydrogeology of the North Ramp boreholes will be prepared, and monitoring of Hydrologic Research Facility boreholes, and all boreholes instrumented in FY 1995 will be monitored.

Air-permeability testing will be conducted in the boreholes scheduled for instrumentation in 1995: USW NRG-6, USW SD-12, and USW UZ-7/7a. A report documenting the air-permeability testing results to date will be prepared. A second air-permeability testing field unit will be constructed to allow cross-hole testing. As boreholes are drilled and samples processed over the next year, a compilation of the extensive data set of matrix hydrologic properties will be used to produce an estimate of hydrogeologic units over the entire site. All lithologic units present at Yucca Mountain will be addressed and means and standard deviations of all physical and hydrologic properties, along with modeling parameters will be provided for the hydrogeologic units including a consideration of the spatial distribution of the properties. This will be assisted by the planned effort to evaluate unsaturated flow measurement and estimation methodologies.

3.1.8 Study 8.3.1.2.2.4 - Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility

The objectives of this study are to supplement and complement the surface-based hydrologic information needed to characterize the Yucca Mountain site, and to provide information for analyzing fluid flow and the potential for radionuclide transport through unsaturated tuff.

Activity 8.3.1.2.2.4.1 - Intact-fracture test in the Exploratory Studies Facility. The objective of this activity is to evaluate fluid-flow and chemical-transport properties of single, relatively undisturbed fractures.

Optical techniques may be used to obtain digital data of the fracture plane topography of single fractures. These data will be used with the data collected from fluid flow tests on single-fracture rock cores. The data will include air and water permeabilities under known applied loads, boundary conditions (gradient), water potentials (fracture plane and matrix), and degree of saturation (fracture plane and matrix) to assist unsaturated, fractured rock modeling efforts. This technique is documented in a report by Cardenas-Garcia and Severson (in prep.).

Preparation continued for the design of an axial-fracture vessel test. The success of these tests will determine the final design of a high-pressure test vessel that will apply hydrostatic pressures on core samples that are equivalent to in situ lithostatic loads. Drawings

of the preliminary design of the high-pressure vessel for testing axial fracture cores were completed.

Activity 8.3.1.2.2.4.2 - Percolation Tests in the Exploratory Studies Facility. The objective of this activity is to determine the hydrologic conditions that control the occurrence of fluid flow within fractures and matrix and to provide experimental data against which the validity of numerical and conceptual models can be tested.

The ponding test continued on a large fractured welded tuff block from the Tiva Canyon columnar unit. The test block dimensions are 54.3 cm long x 47.5 cm wide x 80.6 cm high. Measurements were made of water flow rate at different upper boundary pressures. The water pressure was gradually decreased from -5 to -20 cm of water at the top of the block. The flow rate varied between 400 and 1 cm^3/hour and water flow did not stop. After the top water pressure reached -20 cm of water, it was increased to -15 cm of water. These measurements will allow testing for hysteresis and air blockage effects on unsaturated flow through fractures. A report documents water imbibition measurements in welded tuff rock samples taken from the trimmings of the above mentioned block (Ciesnik et al., in prep.). The effect of air entrapment on maximum achievable water saturation in the matrix was included in this report. The results documented in this report will be used by the modeling study (8.3.1.2.2.8) to test models of water flow through fractured rock.

Activity 8.3.1.2.2.4.3 - Bulk-permeability test in the Exploratory Studies Facility. The objectives of this activity are to determine the scale at which the host rock behaves as an equivalent anisotropic porous medium, to compare hydraulic test results against a distribution of simulated results calculated from a large number of realizations of the possible fracture networks conditioned on average fracture orientation and/or fracture density data, and to use a numerical fracture-flow model to establish the minimum dimensions at which other rock masses with the same fracture characteristics behave as equivalent porous media and to examine the dependence of rock-mass dimensions on changing saturation.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.2.2.4.4 - Radial borehole tests in the Exploratory Studies Facility. The objectives of this activity are to detect vertical movement of water in both the vapor and liquid forms and to evaluate the potential for lateral movement of water along the hydrogeologic contacts as well as to evaluate the radial extent of excavation effects on the hydrologic properties of unsaturated hydrogeologic units.

Air-injection testing in the Alcove #1 radial boreholes began. The radial boreholes tests are required to measure the anisotropy of the Yucca Mountain tuff because anisotropy is important for all gas and liquid flow modeling. The boreholes consist of three 30-m long, near horizontal boreholes drilled in an expanding equilateral triangle. Testing consisted of television logging to identify fractures and breakout zones, and single hole gas-injection testing using a downhole packer system. Over 75 tests have been conducted; however, due to high borehole rugosity some sections of the borehole were not tested. Initial permeability values range from 10^{-13} m^2 up to 10^{-11} m^2. These values are in the same range as the air-

permeability values from the Tiva Canyon Surface-Based Testing and indicate the potential exists for substantial flows of gas and liquid in this part of the Tiva Canyon.

Activity 8.3.1.2.2.4.5 - Excavation Effects Test in the Exploratory Studies Facility. The objective of this activity is to monitor changes to both the stress state and fractured rock permeability caused by excavating. The objective is to use these data, as well as other physical properties gathered during the activity, to validate and calibrate a coupled hydraulic-mechanical finite-element model. The model will be used to predict stress and ensuing permeability changes around excavation openings.

Preliminary locations for this test were chosen to minimize excavation delay without jeopardizing test objectives. The first proposed location (intersection of North Ramp and Calico Hills tunnel) will be reached during FY 1996 and field preparation for this test will occur at the end of FY 1995. Instruments that will be used in this test include (1) packer air-injection strings to measure air-permeability changes around excavated areas, (2) borehole pressure cells to measure changes in rock stress around the first test location, and possibly around successive locations, and (3) borehole extensometers to measure fracture deformation.

Activity 8.3.1.2.2.4.6 - Calico Hills testing in the Exploratory Studies Facility. This activity was deleted from the study plan in Revision 9 of the Site Characterization Program Baseline. Testing in the Calico Hills unit will be conducted as part of other Exploratory Studies Facility test activities and will be described in revisions of the Exploratory Studies Facility study plans.

Activity 8.3.1.2.2.4.7 - Perched-water test in the Exploratory Studies Facility. The objectives of this study are to detect the occurrence of any perched-water zones; to estimate the hydraulic properties of the zones; and to determine the implication of the existence of such zones on flux, flow paths, and travel times.

Monitoring to detect the occurrence of perched water in the Exploratory Studies Facility Starter Tunnel and Alcove #1 was continued during this reporting period without detecting any perched water. A report by Burger and Scofield (in prep.) relates the occurrences of perched water in surface-based boreholes to projections of possible perched water within the Exploratory Studies Facility. This report compiles, documents, and interprets hydrologic and geologic information on five boreholes where perched water has been encountered. Fracture density, stratigraphy, and matrix properties were used to evaluate the character of the perched water zones.

Activity 8.3.1.2.2.4.8 - Hydrochemistry tests in the Exploratory Studies Facility. The objectives of this activity are to understand the gas transport processes within the unsaturated zone and to provide independent evidence of flow direction, flux, and travel time of gas; to design and implement methods for extracting uncontaminated pore fluid from rock excavated during ramp construction; to determine the flow direction, flux, and travel time of water in the unsaturated zone by isotope geochemistry techniques; and to determine the extent of the water-rock interaction so that geochemical modeling can be performed to deduce the flow path and to understand the geochemical evolution of the unsaturated zone water.

Four hundred core samples of densely welded Tiva Canyon Tuff were collected during the drilling of the three radial boreholes in Alcove #1 of the Exploratory Studies Facility. Of the 400, 251 core samples were used for a core-packaging study conducted by Los Alamos. The water extracted from the remaining 149 core samples, will be used for analysis of major ions and stable isotopes. Testing of these samples will begin in late September.

Initial pumping of the radial boreholes in Alcove #1 to remove the SF_6 tracer failed to recover any measurable amounts of SF_6. The absence of tracer gas in the boreholes may be caused by the ventilation system in the Exploratory Studies Facility, which may remove the natural rock gases in the immediate vicinity of the Exploratory Studies Facility, or it may be indicative of a large permeability of the rocks in the vicinity of the Starter Tunnel which, when coupled with the shallow depth of the Starter Tunnel, may allow free exchange between the rock gas and the atmosphere.

Activity 8.3.1.2.2.4.9 - Multipurpose-borehole testing. This activity was deleted from the study plan in Revision 10 of the Site Characterization Program Baseline. In the current Exploratory Studies Facility design with two ramps, testing is no longer planned in a scientific shaft. This activity was originally planned to monitor hydrologic and engineering interference effects from construction of Exploratory Shafts 1 and 2 on tests in these shafts and interference effects between tests in the shafts.

Activity 8.3.1.2.2.4.10 - Hydrologic properties of major faults encountered in Main Test Level of the Exploratory Studies Facility. The objective of this activity is to investigate the permeability and flow conditions of the major faults encountered in the ramps and in drifts at both the Calico Hills and Topopah Spring levels of the Exploratory Studies Facility.

Planning continued to test the Bow Ridge fault in Alcove #2.

Forecast: Borehole testing will continue in the three radial boreholes constructed in the upper lithophysal zone of the Tiva Canyon Tuff in Alcove #1 in the Starter Tunnel. Testing will consist of single-hole and cross-hole air-injection testing to determine in situ permeabilities, hydrochemistry gas sampling to determine composition and residence of gases in the unsaturated zone, and shut-in pressure monitoring to determine the connectivity of fractures in the boreholes.

Monitoring for perched water will occur during construction of the North Ramp and any alcoves constructed from the North Ramp. Testing is planned if perched water is encountered during Exploratory Studies Facility construction. Surface-based boreholes drilled in the vicinity of the Exploratory Studies Facility will be monitored for the occurrence of perched water. If perched water is encountered in the Exploratory Studies Facility or surface-based boreholes, a report describing the hydraulic characteristics and water chemistry will be issued.

Testing in additional alcoves will include: radial borehole testing to determine in situ air-permeability, unsaturated-zone hydrochemistry testing on gaseous and aqueous samples extracted from core and borehole samples. Gaseous-phase circulation testing will be

conducted to determine the natural, primarily barometrically driven, flow of air and water vapor within the vicinity of the Exploratory Studies Facility. Hydrologic properties of major faults may be tested to determine the hydraulic properties, mostly permeability, of any major structural features encountered in the Exploratory Studies Facility.

The intact fracture activity will test low- and high-pressure vessels (confining cells) using axially-fractured, nonwelded and welded core samples. Gaseous and aqueous phase tests will be conducted to characterize the movement of fluids through fractures under various confining pressures. Inspection trips will be made to the Exploratory Studies Facility to identify potential locations for fracture sampling sites.

Test plans (technical and logistical) will be developed for conducting Percolation Tests on two, 2-m cubic blocks of tuff to be excavated in North Ramp Alcoves #3 and #4. Emphasis will be on details of construction and testing support. Fluid flow tests will continue on the large block in the fractured-rock hydrology laboratory to study the hysteretic behavior of water flow through fractures. Data on hysteresis are needed to improve design of the Exploratory Studies Facility tests.

3.1.9 Study 8.3.1.2.2.5 - Diffusion tests in the Exploratory Studies Facility

The objective of this study is to determine in situ the extent to which nonsorbing tracers diffuse into the water-filled pores of the tuffs of the Topopah Spring welded unit at the Main Test Level of the Exploratory Studies Facility. A diffusion test is also proposed in the Calico Hills unit.

No progress during this reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

3.1.10 Study 8.3.1.2.2.6 - Characterization of Gaseous-Phase Movement in the Unsaturated Zone

The objectives of this study are to describe the pre-waste emplacement gas-flow field; to identify structural controls on fluid flow; to determine conductive and dispersive properties of the unsaturated zone for gas flow; and to model the transport of water and tracers in the gas phase.

Activity 8.3.1.2.2.6.1 - Gaseous-phase circulation study. The objectives of this activity are to determine the air circulation in open boreholes USW UZ-6 and USW UZ-65 as a function of barometric pressure and air temperature; to reconstruct the air-circulation history for these boreholes from the time of borehole emplacement to the time of measurement; to determine the zones in which most gas exchange occurs based on logs of flow, temperature, and gas composition with depth; to determine near-field air conductivities, storativity, and

anisotropy; and to develop a data base suitable for calibrating gas-phase circulation models for the unsaturated-zone at the Yucca Mountain site.

Shut in pressure testing continued at UE-25 NRG#4 through August. Shut in pressure tests at UE-25 NRG#2b, UE-25 NRG#3, and UE-25 WT#18 were begun in September 1994. The results of these tests will allow determination of ambient gas circulation characteristics prior to excavation of the North Ramp of the Exploratory Studies Facility.

A downhole vertical, directional, air-flow indicator was constructed and tested at the Nevada Test Site. This instrument will be used for downhole air flow logging to define specific flow zones within the unsaturated units.

Data from a divergent tracer test from USW UZ-6s to the nearby Hilti holes indicate that the conceptual model governing the test design, and the practicality of using divergent tests are both questionable. A new series of tracer testing that involves convergent test methods and thermal convection as a major element has been developed and will be employed in November during a tracer test from USW UZ-6 and USW UZ-6s.

One of two tracer gases approved for injection at Yucca Mountain, 1,1,1,2-tetraflouroethane, (CH_2 FCF_3), had previously been undetectable using existing gas chromatographs. In September, modifications were made that initially indicate that CH_2 FCF_3 will be detectable at a limit of about 0.1 ppm and qualitative detection may be as low as 0.01 ppm. This means that CH_2 FCF_3 may be a usable alternative to SF_6 for tracer testing, which is important because the widespread use of SF_6 around Yucca Mountain has resulted in high background concentrations in unsaturated-zone gases limiting its value as a tracer gas.

Forecast: Selected boreholes will be monitored for pressure flow and gas chemistry before, during, and after the tunnel boring machine passes to establish the effects of Exploratory Studies Facility North Ramp excavation. A series of convergent tracer tests will be conducted to test the validity of various conceptual models governing gas-phase flow near Yucca Mountain. Efforts to simulate the results of the airflow, pressure, and chemistry data will continue and will contribute to the site-scale unsaturated zone modeling effort. The boreholes will be packed off to monitor pressure changes and to allow for chemistry sampling in multiple zones within each borehole, which will assist in determining flow pathways.

The preferred pneumatic pathways will be examined using a series of vertical profiles across the sites in question. An estimate will be made of the contribution of the pathways to the total evaporative flux. Detection schemes will be developed to locate other pathways with the horizontal scanning capability of the upgraded lidar.

3.1.11 Study 8.3.1.2.2.7- Hydrochemical Characterization of the Unsaturated Zone

The objectives of this study are to characterize the hydrochemistry of the unsaturated zone by determining the transport mechanisms, flow directions, and travel times for gas and

water; determining the extent of water/rock interactions; and developing conceptual hydrologic and geochemical models.

Activity 8.3.1.2.2.7.1 - Gaseous-phase chemical investigations. The objectives of this activity are to understand gas-phase transport mechanisms within the unsaturated zone at Yucca Mountain, as well as to seek evidence of gas-flow direction, volume, rate, and travel time within the unsaturated zone.

Gas samplings from open boreholes in the unsaturated zone were conducted in UZ and NRG boreholes. Sampling methods consisted of (1) simply hanging clusters of nylon tubes of different lengths down the boreholes and pumping formation gas to the surface, and (2) using packers to pack and pump certain borehole intervals for gas sampling. Due to barometric effects, boreholes were both inhaling and exhaling within a 24-hour period. One CO_2 gas sample collected from UE-25 UZ#16 borehole packed off at a depth interval of 477-481 m yielded an apparent carbon-14 age of about 10,800 years, which is consistent with carbon-14 gas data of USW UZ-1. Other samples collected in the intervals to a depth of 183 m had apparent carbon-14 ages ranging from modern to 2,600 years.

A laboratory batch-type testing procedure was developed that provides a simple, rapid, and reproducible method to investigate the sorptive characteristics of crushed materials for gas tracers. Batch tests were conducted to determine the retention time of sulfur hexafluoride on crushed volcanic tuff, gypsum cement, and clinoptilolite. From the test results, equilibrium adsorption constants and retention equations were derived for each mineral and tuff. The equilibrium adsorption constants show that sulfur hexafluoride is readily adsorbed onto clinoptilolite, bedded tuff, and Topopah Spring Member tuff, but is not appreciably adsorbed onto gypsum cement, Tiva Canyon Member tuff, or Pah Canyon Member tuff. The similarity in retention equations for all but one of the volcanic tuffs shows that the surface area of each volcanic tuff is a good indication of the sorptive capability of the tuff. The equilibrium adsorption constants and the surface areas of the volcanic tuffs are primarily controlled by the amount of zeolite in the tuff. Rattray et al. (in prep.) will describe results of this testing.

Activity 8.3.1.2.2.7.2 - Aqueous-phase chemical investigations. The objectives of this activity are to design, test, and implement methods for pore-water extraction from core samples; to obtain hydrochemical data to evaluate ground-water flow direction, flux, and travel time in the unsaturated zone; to evaluate extent of water-rock chemical interactions; and to model geochemical evolution of water in the unsaturated zone.

Perched water from USW NRG-7/7a near the top of the Calico Hill, collected March 7, 1994, has an apparent carbon-14 age of about 3,300 years. Pore water extracted by high-pressure compression on UE-25 UZ#16 cores of Calico Hills yielded apparent carbon-14 ages ranging from about 1,000 to 5,000 years. Field reports for Borehole USW SD-9 on July 6, 1994, indicated seepage of water from the borehole wall at about 411 m in the Topopah Spring Member as seen by video camera.

The triaxial compression method can successfully extract representative pore water from Yucca Mountain nonwelded tuffs having initial moisture contents as low as 8 percent by

weight. The one-dimensional compression method can successfully extract representative pore water from nonwelded tuffs with initial moisture contents as low as 7.6 percent and welded tuffs with initial moisture contents as low as 6.5 percent by weight. Pore-water chemistry of samples obtained by both triaxial compression and high-speed centrifugation are comparable, indicating that representative pore-water chemistry can be obtained by compression methods. Yang et al. (in prep.) document these results.

Intact 3.27-inch-to 3.34-inch-(8.3 cm to 8.5 cm) diameter cores were chiseled to fragment chips for compression because the core is oversized and too large for existing compression cells (approximately 2.44-inch-[6.2 cm] diameter cores). Compression tests on chips indicated that samples should be double wrapped in Teflon during compression to minimize the chances of scouring damage to the sample sleeve of the test cell.

Development, validation, and documentation of test methods for the one-dimensional compression and high-pressure one-dimensional compression methods of pore-water extraction are discussed by Higgins et al. (in prep.). The one-dimensional compression cell has a maximum compressive stress rating of 552 MPa. Results from 86 tests indicated that the minimum degree of saturation for successful extraction of pore water from nonwelded tuff was about 14 percent and for densely welded tuff was about 61 percent. The high-pressure one-dimensional compression cell has a maximum compressive stress rating of 827 MPa. Results from 109 tests indicated that the minimum degree of saturation for successful extraction of pore water from nonwelded tuff was about 7.5 percent, and for densely welded tuff was about 34 percent.

Forecast: Gas samples will be collected, analyzed, and tabulated from newly instrumented boreholes. A report presenting the intermediate evaluation of unsaturated-zone hydrochemistry at Yucca Mountain, based on the available gaseous-phase data to date, will be prepared. Pore water will be extracted from core samples from USW UZ-14 and UE-25 UZ#16 and analyzed for cations, anions, and isotopic compositions. Perched water, if encountered, will be analyzed. A report describing the evaluation of unsaturated zone hydrochemistry at Yucca Mountain, based on the aqueous data available to date, will be prepared.

3.1.12 Study 8.3.1.2.2.8 - Fluid Flow in Unsaturated, Fractured Rock

The objective of this study is to develop and refine conceptual and numerical models describing both gas flow as well as liquid water and solute movement in unsaturated, fractured rock.

Activity 8.3.1.2.2.8.1 - Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock. The objective of this activity is to develop detailed conceptual and numerical models of fluid flow and transport within unsaturated, fractured rock at Yucca Mountain.

Numerical simulations were made to match measured flow through a block of partly-welded fractured tuff. Measured saturations and potentials in the fractures generally matched expected values, but additional simulations are needed to refine and evaluate flow parameters. Final flow parameters will be used to help guide site scale fracture flow simulations. A three-dimensional fracture network of the Exploratory Studies Facility portal and Alcove #1 area is being developed as mapped fracture data become available. Censoring techniques have been used to transpose mapped fracture lengths into fracture radii (mean and standard deviation). The technique shows that fracture size may follow a power law distribution instead of previously used lognormal distribution. Two primary and two secondary fracture orientations have been identified that generally follow mapped fault and lineament trends of the Yucca Mountain area. A new semi-analytical method for simulating flow in fractured rocks using a source/sink term for fracture/matrix flow interactions is described in Zimmerman et al. (in prep.).

Activity 8.3.1.2.2.8.2 - Validation of conceptual and numerical models of fluid flow through unsaturated, fractured rock. The objective of this activity is to evaluate the reasonableness of the concepts on which the models developed under Activity 8.3.1.2.2.8.1 are based, by using the results of laboratory tests and tests performed in the Exploratory Studies Facility to access the adequacy of model performances.

No progress during the reporting period; this was an out-year activity.

Forecast: Continue compilation of borehole, pavement, and outcrop fracture data to be used as input to simulate fracture flow at a site scale. The Exploratory Studies Facility portal three-dimensional fracture network and fracture flow modeling will be refined as new data becomes available. Air permeabilities measured from the radial boreholes, Alcove #1, will be used to quantify conductive fracture intensities and fracture transmissivity distributions. The product will be a numerical model of unsaturated water and gas flow in a three-dimensional fracture network of the Exploratory Studies Facility portal area. The Exploratory Studies Facility portal fracture and flow modeling will then be expanded to a site scale for the Tiva Canyon unit.

Effective medium theory and percolation theory will be used to develop a procedure for determining the proper gridblock-scale hydraulic conductivity of a network of variable-aperture fractures. The semi-analytical dual-porosity module that has been written for the TOUGH simulator will be interfaced with the three-dimensional site-scale model. The inverse procedure that has been developed for determining the unsaturated hydraulic conductivities of Yucca Mountain tuffs from measurements of sorptivity and water retention curves will be refined and tested against more recently measured values. An analytical method will be developed to estimate the effect of particle-size distribution on the hydraulic conductivity of near-surface soils at Yucca Mountain.

3.1.13 Study 8.3.1.2.2.9 - Site Unsaturated-Zone Modeling and Synthesis

The objectives of this study are to develop appropriate conceptual models for the site unsaturated-zone hydrogeologic system; to select, modify, or develop numerical hydrologic models capable of simulating the hydrogeologic system and its component subsystems; to apply the models to predict the system response to changing external and internal conditions; to evaluate the accuracy of the models using stochastic modeling, conventional statistical analyses, and sensitivity analyses; and to integrate data and analyses to synthesize a comprehensive qualitative and quantitative description of the site unsaturated-zone hydrogeologic system under present as well as probable, or possible, future conditions.

Activity 8.3.1.2.2.9.1 - Conceptualization of the unsaturated-zone hydrogeologic system. The objectives of this activity are to develop conceptual models for the overall moisture flow system within the unsaturated zone at Yucca Mountain and to develop an internally consistent set of hypotheses that describe those aspects of the site hydrogeologic system that are needed to assess the capability of the site to isolate nuclear waste for a period of 10,000 years or longer.

Numerical simulations demonstrated that long-term infiltration beneath Pagany Wash has been high relative to that estimated from recent observations. The importance of lateral flow in diminishing peak surface fluxes and delaying the arrival of surface-derived moisture at the potential repository horizon has also been demonstrated by simulation studies (Kwicklis et al., 1994).

Topographic and stratigraphic data were compiled and used to create a computational mesh compatible with TOUGH2 input requirements for a three-dimensional numerical model of gas circulation in the Yucca Crest area around Boreholes USW UZ-6 and USW UZ-6s. Several simulations were run on a simplified two-dimensional mesh employing average annual temperature conditions to observe temperature-induced buoyancy-driven flow. These results were compared with analyses of the gas-phase flow system based on gas isotope data. The modeling results appeared to be generally consistent with the principal conclusions derived from analysis of that data, including rapid transport within the Tiva Canyon, the effectiveness of the PTn in segregating the flow system into shallow (TCw) and deeper (TSw) components, and relatively small advective flow velocities within the TSw unit, except possibly near outcrops along the Solitario Canyon escarpment.

A method described by Lu (1994) outlines the theoretical framework and performs test cases on the particle tracking algorithm currently being coupled with TOUGH2. The particle tracking algorithm was used with TOUGH2 as a post-processor of pore-velocity information. TOUGH2 was modified to output pore velocity information at times identified by the user.

Activity 8.3.1.2.2.9.2 - Selection, development, and testing of hydrologic-modeling computer codes. The objectives of this activity are to select, evaluate, and adapt existing numerical hydrologic-modeling codes for application to the site unsaturated-zone hydrogeologic system; and to modify existing codes or develop new codes, as needed, to simulate particular problems or aspects that are unique to the Yucca Mountain system.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.2.2.9.3 - Simulation of the natural hydrogeologic system. The objectives of this activity are to construct appropriate hydrologic models for the natural site hydrogeologic system to simulate and investigate the present existing state of the system and to predict probable future and past states of the system under changes in the environmental conditions.

The development of the three-dimensional site-scale model of the natural site hydrogeologic system of Yucca Mountain continued. New data were received, reviewed and incorporated, as needed, into the model. Various analyses were performed including subdivision of the Calico Hills unit into zeolitic and vitric facies. A new fault map was received and evaluated for incorporation into the site-scale model. New rock property data were also incorporated into the model. A comprehensive report documents the foundations and preliminary results of the site-scale model of Yucca Mountain (Wittwer et al., in prep.).

Various three-dimensional numerical simulations of moisture flow within Yucca Mountain were conducted using alternative assumptions regarding areal distribution of infiltration and hydrologic properties of faults. Results obtained using a recent map of estimated infiltration show fracture-dominated flow in the welded units in the high infiltration areas (>1 mm/yr) and matrix-dominated flow elsewhere. Simulation results indicate that where fracture flow dominates, water takes less than 10,000 years to reach the water table, but on the order of 10^6 years where matrix flow is dominant (Bodvarsson et al., 1994).

The effects of gas flow and the geothermal gradient have been incorporated into the site-scale model, but no rigorous model calibrations have yet been performed. Comparison between observed and calculated temperature profiles show reasonably good agreement. Gas flow can have significant effects on moisture flow when the latter is small, and will be considered in future simulations.

A new module in the TOUGH2 code, EOS9, was developed. This module allows a solution to only the Richard's equation, thus neglecting variations in temperature and gas flow. The module was tested using various one-, two- and three-dimensional saturated and unsaturated flow problems and was found to be 5 to 10 times faster than the conventional TOUGH2. This increase in computational speed results from only solving one equation, rather than three equations, per grid block. This new module will be useful for sensitivity studies where many similar simulations must be performed, or for cases in which the effects of temperature and gas flow would be expected to exert only secondary effects (e.g., scenarios involving wetter future climate and relatively high infiltration rates).

The North Ramp of the Exploratory Studies Facility has been incorporated into the site-scale model through the use of a new sub-gridding technique. This will allow predictions to be made regarding pressure, temperature, and saturation conditions encountered in the Exploratory Studies Facility as well as changes due to excavation of the Exploratory Studies Facility itself.

Activity 8.3.1.2.2.9.4 - Stochastic modeling and uncertainty analysis. The objective of this activity is to assess the probable limits of uncertainty of numerical-model predictions caused by uncertainties in the material-property and boundary-condition data.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.2.2.9.5 - Site unsaturated zone integration and synthesis. The objective of this activity is to integrate all applicable site data and analyses to synthesize a continually updated, comprehensive representation for the site unsaturated-zone hydrogeologic system.

No progress during the reporting period; this was an out-year activity.

Forecast: The hydrologic implications of heat flow data and studies of the fracture-filling materials will be assessed and incorporated into the construction of the numerical model.

The numerical modeling of gas flow at Yucca Crest will continue. After preliminary modeling using two-dimensional mesh has been used to identify controlling processes, the three-dimensional model will be calibrated using the measured air-flows at USW UZ-6s. Once the model has been calibrated to reproduce the observed flow of air, the model will attempt to reproduce the results of planned tracer tests. After having been calibrated and tested with borehole effects in the model, the borehole will be removed and the airflow that occurs in the absence of the borehole will be simulated so that the effects of natural air circulation on moisture and heat redistribution can be estimated.

The spatial structure of the permeability measurements obtained from air-permeability tests at UE-25 UZ#16 and USW NRG-7/7a will be identified using geostatistical or fractal-scaling techniques to facilitate the extrapolation of these values to locations for which no measurements will be available.

The three-dimensional Site Model will be calibrated using measured hydrologic properties and available in situ saturation and water potential data from surface-based boreholes. The model will be further tested and calibrated using available isotope data (^{36}Cl, ^{3}H and ^{14}C) and observations of seeps or perched water from excavation of the Exploratory Studies Facility. Predictions will be made for new borehole locations as a means of further testing the model.

The numerical grid of the site-scale model will be extended in all directions to include most of the wells in the area, important faults such as the Solitario Canyon and Bow Ridge faults, and the steep gradient in the water table towards the north. The numerical grid generation will include the entire Exploratory Studies Facility in a flexible manner.

3.1.14 Study 8.3.1.2.3.1 - Characterization of the Site Saturated-Zone Ground-Water Flow System

The objective of this study is to obtain the hydrologic data needed to describe ground-water flow paths, fluxes, velocities, and travel times within the site saturated-zone geohydrologic system at Yucca Mountain.

There was no activity on the study plan during this reporting period.

Activity 8.3.1.2.3.1.1 - Solitario Canyon fault study in the saturated zone. The objectives of this activity are to characterize the hydrologic nature, significance, and implications of the Solitario Canyon fault, as well as to determine if the fault is a barrier to eastward flow of water in the saturated zone beneath the repository block.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.2.3.1.2 - Site potentiometric-level evaluation. The objectives of this activity are to analyze the character and magnitudes of potentiometric-level fluctuations with depth and time to estimate transmissive and storage properties, to measure water-level variation with time to determine hydraulic gradient, to correlate water-level variations with earth crustal strain changes, to better define altitude distribution of uppermost potentiometric surface; to determine barometric and dilatational efficiency, and to determine the frequency response function of the well/formation to barometric and earth-tide induced strains.

Monitoring of water levels in the saturated zone at Yucca Mountain continued. Monthly water-level measurements were made in 18 wells. Hourly water-level data were collected from 17 zones in 12 wells, and continuous data were obtained in four zones in two wells. Additional water-level measurements were made in support of other activities at USW NRG-7/7a, USW SD-9, and USW UZ-14. These measurements have provided additional insights to the character of the "large hydraulic gradient" area north of Yucca Mountain. Water levels have essentially remained stable during the reporting period. Three reports will document water levels and water level changes in the Yucca Mountain area with Tucci et al. (in prep.) describing water levels in 1990-91, O'Brien et al. (in prep.) focusing on 1992, and Boucher (in prep.) describing J-11 and J-12 data for 1989-91. Reduction, evaluation, and review of all 1993 water-level data was completed.

Four zones in two wells were monitored continuously to detect water-level fluctuations caused by earthquakes and underground nuclear testing. Water-level fluctuations associated with the September 1, 1994, magnitude 7.1 earthquake off the coast of northern California were detected but were relatively small (less than 1.5 m), and water levels returned to pre-earthquake levels in less than one hour.

Plans for cleaning, reconfiguring, and hydraulic testing of 15 WT-series wells were completed. Testing of these existing wells would provide a much better understanding of the hydrologic system. Reconfiguration of the network of hourly and monthly monitored wells to

obtain hourly water-level data that may be used to estimate aquifer properties in four additional wells was completed.

The precision and accuracy of water-level measurements made at Yucca Mountain is important if water-level changes or trends and potentiometric gradients are to be identified and quantified (Boucher, 1994). Work was begun on updating the potentiometric-surface map for 1993 conditions and on analysis of water-level trends for 1988-93. Such information will provide valuable input to the site saturated-zone, three-dimensional, ground water flow model.

Activity 8.3.1.2.3.1.3 - Analysis of single- and multiple-well hydraulic-stress tests. The objectives of this activity are to determine intraborehole flow profiles for each of the C-wells under static and pumping conditions, to correlate intraborehole flow rates with lithology and fractures, to identify test-scale hydrologic boundaries, and to estimate aquifer properties (e.g., transmissivity, storage coefficient).

In preparation for long-term hydraulic testing, 1983-84 C-hole pumping and injection test data were analyzed by using type-curve matching techniques developed for confined, leaky-confined, unconfined and fissure-block aquifers. Eleven transmissive intervals were identified at the C-hole complex. Injection tests in UE-25 c#1 established a permeability profile for the C-hole complex that suggests water is transmitted by faults, fractures, partings between geologic units, and intervals with relatively large matrix permeability. The pumping tests indicated a change from an unconfined to a confined aquifer with depth and increasing transmissivity toward faults that intersect the C-holes. For the entire thickness of rocks penetrated by the C-holes, cross-hole pumping and injection tests indicated an average transmissivity between 20,000 and 35,000 feet^2 per day; an average storativity between 0.002 and 0.004; an average horizontal hydraulic conductivity between 30 and 40 feet per day; and an average vertical to horizontal anisotropy of 0.2. The results of this analysis are documented in Geldon (in prep.).

Activity 8.3.1.2.3.1.4 - Multiple-well interference testing. The objectives of this activity are to discriminate between equivalent-porous-medium and fracture-network models at the scale of the tests, to determine effective aquifer properties (e.g., transmissivity, storage coefficient), and to evaluate the three-dimensional nature of the flow field in the test vicinity.

Background pressure data from packed-off zones in wells UE-25 c#1, c#2, and c#3, collected during the period from January to April 1994, were developed from raw transducer-voltage signals. These data will be analyzed for the effects of atmospheric pressure loading and earth tides to obtain barometric efficiency and aquifer characteristics.

The USGS Modular Ground Water Flow (MODFLOW) program is being used to develop a three-dimensional equivalent-porous-medium model of the C-hole complex. The model grid consists of 31 columns and 24 rows; it extends from the Fran Ridge fault on the east to the Bow Ridge fault on the west and from about 610 m south of the C-holes to about 1829 m north of the C-holes. Input variables are based largely on results of 1983-1984 pumping tests at the C-holes under the assumption that vertical changes in hydrologic properties with depth in the C-holes result from proximity to faults and hence, can be

extrapolated laterally with respect to faults. The model will test the influence of faults on water movement in the vicinity of the C-holes. Model results will be calibrated against heads measured in the C-holes, UE-25 p#1, and UE-25 WT#14 during June 1993, head changes during the 1983-84 C-hole pumping tests, and intraborehole flows in the C-holes measured by heat-pulse flowmeter surveys. When calibrated, the model will be used to predict head changes from planned pumping tests in the C-holes.

Planned hydraulic-stress and tracer tests in fractured, tuffaceous rocks below the water table at Yucca Mountain will require work at depths in excess of 400 m. To facilitate prototype testing of equipment and methods to be used in aquifer tests and tracer tests at Yucca Mountain, an analog site was selected in the foothills of the Sierra Nevada near Raymond, California. Two of nine 75- to 90-m-deep wells drilled into fractured, granitic rocks at the Raymond site have been instrumented with packers, pressure transducers, and other equipment that will be used at Yucca Mountain. Single-well pressure-injection profiling tests, to determine the vertical range in near-well horizontal permeability, were conducted in all nine holes. A paper was presented at the 1994 High-Level Waste Conference summarizing this prototype testing (Umari et al., 1994).

Activity 8.3.1.2.3.1.5 - Testing of the C-hole sites with conservative tracers. The objectives of this activity are to determine aquifer transport properties, to evaluate applicability of equivalent-porous-medium models vs. fracture network models, to evaluate adequacy of single-well tests versus multiple-well tests to characterize hydraulic properties, and to evaluate spatial correlation and scale dependency of transport parameters.

At the fractured granite analog site for the planned hydraulic-stress and tracer tests at the C-hole complex, located in the Sierra Nevada near Raymond, California (see Activity 8.3.1.3.1.4), two multiple-well convergent tracer tests, and one two-well recirculating tracer test were conducted to date. Fluorescein, potassium iodide, deuterium, and fluorescent microspheres were used as tracers, and a tracer-injection packer string, specially designed to ensure that all the tracers evacuate the borehole and enter the ground water flow system was used in the last two tests. The results of the tracer tests indicate that it is difficult to arrive at a unique interpretation of tracer test results in fractured rock. This highlights the value of intermingling tracer tests with hydraulic tests and not waiting to complete all hydraulic testing before tracer tests are started. The hydraulic and tracer testing program at the C-holes will be modified accordingly to allow for this intermittent execution of hydraulic and tracer tests.

Progress was made toward completion of the tracer injection and sampling system to be used during the upcoming tracer tests. A stainless steel tracer-holding tank was designed and its procurement initiated. All the design components of the surface-based automated-sampling system that will be controlled by the PC-based computerized Data Acquisition System were identified. Actual construction of the sampling system will commence in FY 1995. Other requirements of the tracer-injection system, such as surface-based plumbing, and assembly of the already-procured downhole part of the tracer-injection system, have been requested from Nevada Test Site contractors by a Criteria Letter.

Activity 8.3.1.2.3.1.6 - Well testing with conservative tracers throughout the site. The objectives of this activity are to determine aquifer transport properties at selected site locations; to evaluate vertical and horizontal spatial variability of flow parameters; and to examine spatial correlation, cross correlation, and scale dependency of flow and transport parameters.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.2.3.1.7 - Testing of the C-hole sites with reactive tracers. The objective of this activity is to characterize the chemical and physical properties of the geologic media in the saturated zone in the vicinity of the C-holes that will affect radionuclide retardation during ground-water flow within the saturated zone.

To test the validity of previously collected batch sorption data (from Study 8.3.1.3.6.1) and to predict transport behavior at the laboratory scale, YMP scientists were collecting data on a second phase of column transport experiments using a lithium bromide tracer. Preliminary breakthrough curves suggested that the diffusion coefficients needed to match the tracer results are of the same order of magnitude as diffusion coefficients measured in rock beaker experiments by Study 8.3.1.3.6.1

Project scientists demonstrated (at laboratory scale) the validity of the matrix-diffusion model for transport of a dissolved species. This is significant because if this model applies at Yucca Mountain, then the saturated zone would be established as a significant barrier to radionuclide migration, thus providing additional confidence in the suitability of the Yucca Mountain site. Data collection was completed, and a paper describing simultaneous transport of synthetic colloids and a nonsorbing solute through single saturated natural fractures was being prepared (Reimus et al., in prep.). In these experiments, tests using iodide and polystyrene microsphere tracers were conducted in three fractured tuff samples: one Bandelier tuff fracture and two C-wells specimens. The tracer breakthrough curves for the three fractures were similar. In each case, the microsphere tracers arrived at the outlet approximately 10 percent sooner than the dissolved tracer and the dissolved tracer exhibited a significantly more gradual approach to the steady-state concentration than did the microspheres, which probably results from the different diffusion coefficients of each tracer. The reason for the extremely small diffusion coefficient of the microspheres may be that some tracer remained in the center of the fracture, an area in which flow velocities are higher. Furthermore, microspheres cannot diffuse into the rock matrix like the dissolved tracer. Thus, the gradual rise of the breakthrough curve of the dissolved tracer was probably caused by matrix diffusion, which delayed the arrival of a significant portion of the tracer at the outlet.

Extensive software documentation and QA efforts continued for the FEHMN application, a three-dimensional, multiphase heat and mass transfer code.

Activity 8.3.1.2.3.1.8 - Well testing with reactive tracers throughout the site. The objective of this activity is to characterize chemical and physical properties of the geologic media in the saturated zone throughout the site that will affect radionuclide retardation during ground-water flow within the saturated zone.

No progress during the reporting period; this was an out-year activity.

Forecast: The C-wells tests will demonstrate the applicability of laboratory sorption measurements for predicting field transport behavior using a model of fluid flow and transport in fractures, coupled to transport via molecular diffusion with the surrounding rock matrix. This model, if shown to be valid, would add several orders of magnitude to the radionuclide migration time in the saturated zone above that predicted for pure fracture flow and transport. The polystyrene microsphere part of the study will show whether colloidal-sized particles can transport over field scale distances in the saturated zone.

The variable-speed controller and transformer unit, and the four-conductor cable required to operate the 200 gpm pump to conduct cross-hole hydraulic and tracer tests at the C-hole complex, will be procured and delivered to the C-holes pad. The packer strings will be removed from the C-holes to replace the Direct Current (DC) - voltage pressure transducers with more accurate quartz crystal frequency transducers with ASCII output. The packer strings will be reconfigured, and components will be added to the reconfigured string, to allow for the conduct of tracer tests intermittently with cross-hole hydraulic tests. Also, the 200 gpm pump, encased in a pump shroud, will be deployed in one of the C-holes. The long-awaited cross-hole hydraulic- and tracer-testing program will commence.

3.1.15 Study 8.3.1.2.3.2 - Characterization of the Saturated-Zone Hydrochemistry

The objective of this study is to describe the composition of, and spatial compositional variations in, saturated-zone ground waters using new and extant data; to identify the chemical and physical processes that influence ground-water chemistry; and to aid in the identification and quantification of fluxes to, from, and within the saturated zone.

Activity 8.3.1.2.3.2.1 - Assessment of saturated-zone hydrochemical data availability and needs. The objectives of this activity are to compile and evaluate extant hydrochemical data for the saturated zone, to identify data deficiencies and potential sampling sites and assemble requisite material for sample and field data collection, and to augment extant information by collecting and analyzing new hydrochemical samples and data.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.2.3.2.2 - Hydrochemical characterization of water in the upper part of the saturated zone. The objectives of this activity are to describe the hydrochemistry of the upper part of the saturated zone by collecting representative water samples from intervals within the upper 100 m of the saturated zone, within and adjacent to the site area, and studying their chemical and isotopic compositions; and to estimate flux to or from the saturated zone by collecting interstitial water and gas samples from immediately above the water table and studying their chemical and isotopic compositions.

Additional chemical and stable and radioisotopic data were identified, compiled, and assessed, then added to the original data set established by Perfect et al. (in prep.). These

data will augment the utility of the original data base, principally because the stable isotopic data improve the capability to address regional, inter-basin ground water flow.

Cuttings from USW UZ-14 and bailed water samples of apparently perched fluids from USW NRG-7/7a and USW SD-9 were collected for analyses. Partial results from the USW NRG-7/7a sample indicate the presence of drilling fluid and possibly attendant drilling contaminants, likely from USW G-1, in the sample. The relative amount of drilling fluid in all perched samples collected to data still cannot be quantified.

Activity 8.3.1.2.3.2.3 - Regional hydrochemical tests and analyses. The objective of this study is to describe regional spatial variations in ground-water chemistry in the saturated zone by collecting representative water samples from wells and springs within the region and by studying their chemical and isotopic compositions.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.2.3.2.4 - Synthesis of saturated-zone hydrochemistry. The objectives of this study are to describe the saturated-zone hydrochemistry; to identify chemical and physical processes that influence ground-water chemistry; and to aid in the identification and/or quantification of ground-water travel times, climatic conditions during periods of recharge, flowpaths, and fluxes to, from, and within the saturated zone.

No progress during the reporting period; this was an unfunded activity.

Forecast: Samples and field data for selected sites within Death Valley National Monument, delayed from FY 1994, will be collected this year to complete the data set to be used to examine the extent to which the valley functions as a discharge area for the site-area sub-regional ground water system. A report documenting the interpretation of these data will be prepared. Work will begin on renovating the laboratory trailer obtained from the EPA. A contract for purchase of an umbilical hoist system, to be used in data and sample collection in saturated zone boreholes, will be prepared. Some or all requisite borehole-discretization equipment (packers, tubing, sliding-port screens, transducers, etc.) will be purchased during FY 1995. Samples and field data will be collected in the course of clean-out of one to three WT holes. A report summarizing this effort will be prepared. Samples and selected field data will be collected as opportunities present themselves.

3.1.16 Study 8.3.1.2.3.3 - Saturated-Zone Hydrologic System Synthesis and Modeling

The objectives of this study are to synthesize the available data into a model and make a qualitative analysis of how the system is functioning and to represent quantitative observations of hydrogeologic data pertaining to the ground-water flow system in a comprehensive flow model.

Activity 8.3.1.2.3.3.1 - Conceptualization of saturated-zone flow models within the boundaries of the accessible environment. The objectives of this study are to synthesize the

available hydrogeologic data to develop a conceptual model and to make a qualitative analysis of how the site saturated-zone hydrogeologic system is functioning.

Luckey et al. (in prep.) provides the basis for constructing a numerical model of the saturated zone flow system and documents the understanding of the saturated zone flow system.

Various flow codes are being evaluated for use in site-scale numerical modeling, with an emphasis on FEHMN, developed by Los Alamos. FEHMN is a finite-element code capable of representing faults and dealing with heat and transport. This code has been linked to AVS (visualization package) and will be interfaced to Stratamodel (geologic framework model package). Analytical element code(s) are also being considered for use on determining site scale boundaries.

The preliminary regional model for the hydrogeologic framework was examined to see how a more detailed grid around the site area would improve site scale modeling process. This regional hydrogeologic framework model is discussed in Activity 8.3.1.2.1.4.4.

Activity 8.3.1.2.3.3.2 - Development of fracture network model. The objectives of this activity are to develop and evaluate methods for simulating ground-water flow and conservative solute transport in saturated fractured rock beneath Yucca Mountain, to relate results of hydraulic and conservative-tracer tests in wells to fracture-network characteristics at Yucca Mountain, to develop methods for identifying transmissive fracture zones in rocks penetrated by boreholes, and to identify geohydrologic conditions at Yucca Mountain where ground-water flow and conservative solute transport can be properly evaluated using the porous-medium assumption.

The conceptual model of ground water flow at the C-hole complex was prepared (see 8.3.1.2.3.1.3). Although hundreds of fractures have been mapped, only a small percentage appear to transmit water. Hydraulic characteristics of the volcanic rocks at the C-hole complex were obtained after extensive analysis of existing aquifer-test data. The conceptual model was tested, to a limited extent, using fracture-network modeling (FRACMAN); however, the model results were inconclusive.

The solution algorithm for the TRINET fracture-network model was extended to include two-dimensional elements for calculation of flow and transport in rock matrix (Ijiri and Karasaki, 1994). The Cluster Variable Aperture Simulated Annealing inversion code was effective in finding low-permeability anomalies, using synthetic samples. Radial convergent and recirculation tracer tests were conducted at the Raymond field site in California to prototype tests to be conducted at the C-hole complex. Several improvements to the planned tests at the C-hole complex were recommended.

Activity 8.3.1.2.3.3.3 - Calculation of flow paths, fluxes, and velocities within the saturated zone to the accessible environment. The objectives of this activity are to estimate ground-water flow direction and magnitude for input into travel-time calculations; and to

evaluate the porous-media concept and fracture-network concept for determining flow paths, fluxes, and velocities.

No progress during the reporting period; this was an out-year activity.

Forecast: The conceptual model report will be finalized. The conceptual model will be used to build a hydrogeologic framework for the area around Yucca Mountain using the three-dimensional geoscientific information system Stratamodel. Lateral and vertical boundaries for the site saturated zone numerical flow model will be selected. A numerical model grid, likely based on the FEHMN code, will be designed. Preliminary estimates of hydraulic-conductivity data will be developed and input into the flow model. Boundary conditions will be developed using the regional flow model discussed in Activity 8.3.1.2.1.1.4. The link between Stratamodel and FEHMN will be tested and will be used to generate numerical model input arrays.

3.2 GEOCHEMISTRY (SCP SECTION 8.3.1.3)

3.2.1 Study 8.3.1.3.1.1 - Ground-Water Chemistry Model

The objective of this study is to develop a ground-water chemistry model that will initially describe pre-emplacement conditions. Future changes in these properties and processes will then be considered, including changes in infiltration as influenced by climatic conditions; long-term mineralogic changes, particularly those influenced by the thermal pulse from emplaced waste; and changes in the material properties due to the emplaced waste, or possible igneous activity.

Project scientists made progress in understanding the water-rock interactions in silicic volcanic rocks, which will help them define the overall variations in ground water chemistry in the present-day Yucca Mountain flow system. This information will serve as a basis for predicting ground water compositional variations in the far-field environment of the proposed repository. This understanding has resulted primarily from a quantitative comparison of the variations in water chemistry found at Yucca Mountain with the variations in fracture and matrix waters found in the silicic volcanic rocks of Rainier Mesa, located 20 km northeast of Yucca Mountain. It appears that water-rock interactions in the unsaturated zone at Yucca Mountain are kinetically inhibited relative to those at Rainier Mesa, and that the high levels of silica in waters in the soil zone at Yucca Mountain could be a major cause for this inhibition. This conclusion will be tested using laboratory experiments with Yucca Mountain rock samples and ground waters. If the conclusion is supported by these experiments, the modeling of water chemistry within Yucca Mountain would be significantly simplified. On the other hand, if the experiments do not support the preliminary conclusion, the experimental data obtained will be used to develop alternative models for the rock-water interactions. Further research in this area will be conducted during the next reporting period.

A chloride-balance method for calculating average infiltration rates was tested using ground water chemistry data from the unsaturated zone at Yucca Mountain. Estimated

infiltration rates range from 0.3 mm/year at 90 m depth in Well UE-25 UZ#4 to 0.8 mm/yr. at 30 m depth in Well UE-25 UZ#5. These rates apply to waters that infiltrated up to several thousand years ago. Nonetheless, they are not very different from rates derived using physical measurements of more recent infiltration.

Project scientists reviewed and evaluated field and laboratory data on the impact of variations in ground-water compositional parameters on the sorption behavior of the radionuclides of concern. A letter report describing this work was completed (Meijer, in prep.). The scientists also designed a preliminary model of the evolution of ground-water chemistry in the unsaturated zone at Yucca Mountain. This model and corresponding data were used to derive recommendations on ground-water composition for future sorption experiments on the radionuclides of concern. The long-term objective is to create a sorption-coefficient data base that bounds the ranges of expected sorption behavior for each of the radionuclides of concern.

Forecast: Hypotheses about the variables, parameters, and geochemical processes that could affect ground-water composition will be formulated on the basis of a thorough review and evaluation of the literature. Preliminary conceptual models will be developed to provide qualitative understanding of the potential effects of variations in individual or small groups of geochemical parameters and/or processes on ground-water compositions. The potential effects of state variables, chemical parameters, and various geochemical processes will be evaluated. Preliminary conceptual models will be integrated into general conceptual models for the ground-water chemistry of each of the major hydrologic units within Yucca Mountain. Computer simulations will be performed to quantify the processes that appear to control the composition of present-day ground waters in Yucca Mountain and to identify those parameters that have the greatest influence on the composition of the ground waters. The laboratory tests are designed to obtain data that cannot be obtained directly from the literature or to challenge key conceptual models.

3.2.2 Study 8.3.1.3.2.1 - Mineralogy, Petrology, and Chemistry of Transport Pathways

The objectives of this study are to determine the three-dimensional distribution of mineral types, compositions, abundances, and petrographic textures within the potential host rock; and to determine the three-dimensional distribution of mineral types, composition, and abundances in rocks beyond the host rock that provide pathways to the accessible environments.

Activity 8.3.1.3.2.1.1. - Petrologic stratigraphy of the Topopah Spring Member. The objective of this activity is to determine the petrologic variability within the devitrified Topopah Spring Member at Yucca Mountain and to define the stratigraphic distribution of variability.

Results of recent studies by YMP scientists indicate that the mineralogy of the potential host rock at Yucca Mountain is not as well known as data from earlier core samples

indicated, and further studies are needed. A paper by Chipera et al. (in prep.) describes these findings and contains several conclusions:

1. Alteration of vitric tuffs above the Topopah Spring Member is very limited (indicating only limited exposure to water over the last 12 million years). It will therefore be useful to map the extent of this shallow alteration in future drill cores to determine the areas in which percolation flux may have accumulated in the past. This mapping will aid in the overall understanding of unsaturated-zone transport processes.

2. Stratification of silica minerals and opal near the potential repository horizon follows models previously developed from other core studies. It would be useful to understand the systematic distribution of these minerals to be better able to predict the nature of silica dissolution/precipitation under a repository thermal load.

3. The zeolite, stellerite, was found to be common within the devitrified Topopah Spring Member at the potential repository horizon in core from UE-25 UZ#16, contrasting with other core data that indicate no zeolitization of the tuff matrix in the potential repository horizon. If sufficient amounts of thermally sensitive minerals such as zeolites occur closer to the potential repository than previously thought, then present considerations of thermal impact caused by repository heating may be affected, and this issue should be reconsidered at this time.

Results of recent studies (Raymond, 1994) indicate that past silica mobilization in the potential host rock at Yucca Mountain has lead to a significant increase in the porosity of the rock along fractures in the Topopah Spring Member. This type of past alteration provides a site-specific analog of future alteration and changes in porosity under a high-repository thermal load. A report by Raymond et al. (1994) describes studies of fractures and lithophysal cavities within the potential host rock along which natural alteration has resulted in silica leaching during cooling of the tuff. Dissolution of cristobalite along fractures and surrounding lithophysal cavities has resulted in local porosity increases from <1 percent to >12 percent. Secondary mineralization following dissolution of cristobalite includes quartz within the fractures and quartz plus smectite within the dissolution porosity.

Activity 8.3.1.3.2.1.2. - Mineral distributions between the host rock and the accessible environment. The objective of this activity is to determine the three-dimensional distribution chemistry and the total abundance of all major rock-matrix minerals, between the host rock and the accessible environment. The analysis of the three-dimensional stratigraphy will be most heavily weighted toward those units that will first be encountered along potential flow paths away from the repository (i.e., Calico Hills).

Vaniman (1994) established that calcite deposits in the unsaturated zone differ markedly from those of the saturated zone, providing evidence that there is a long-standing difference between saturated and unsaturated deposits and that calcite deposits in the unsaturated zone are not the result of catastrophic water-table rise, as some critics have suggested. Vaniman (1994) describes the results of a chemical and petrographic study of

12 calcite samples from USW G-2 and USW GU-3/G-3. The fracture calcites studied include samples from localities above and below the water table. Trace-element data, collected by instrumental neutron activation analysis, are used in the report to discriminate between drill cores and between calcites occurring above or below the water table. Calcite occurrences in the unsaturated zone include young precipitates that may be used as indicators of pathways of fluid transport in unsaturated tuffs (Whelan et al., 1994). Studies of calcite chemistry and of associated precipitates (especially opal and sepiolite) may also help to constrain the water chemistry of unsaturated zone transport.

Project mineralogists have established that downward transport from a common soil-zone carbonate source is evident for a variety of different calcite types in deeper fractures at Yucca Mountain. Vaniman and Whelan (1994) compiled petrographic, chemical, and stable-isotope data for calcite from surface calcretes and calcite from shallow (<17 m) and deeper (>17 m) fracture calcites. A unique zone of isotopically light carbon at the interface between B and K soil horizons at Yucca Mountain can now be identified; this zone should be avoided in sampling to evaluate paleoenvironments of calcite precipitation in soils, but it is a minor variation compared with the highly variable isotopic signatures of deeper calcites. These variations indicate either time-dependent or location-dependent variations in the isotopic chemistry of recharge waters that pass through the unsaturated zone at Yucca Mountain.

In extensive earlier data collections, YMP scientists found only very limited occurrences of erionite, a known carcinogen and the most potentially hazardous mineral at Yucca Mountain. Guthrie et al. (in prep.) describes this occurrence and also deals with the distributions of less hazardous minerals and minerals of implicated but unproved hazard (mordenite, palygorskite, crystalline silica). It is probable that potential health risks from these other minerals can be readily mitigated. The authors describe the distributions of fibrous minerals at Yucca Mountain and focus on the potential health hazards from inhalation of fibrous zeolites, especially erionite. After this paper was compiled, quantitative x-ray diffraction analyses were completed for another 12 samples from drill core USW UZ-14. These samples, representing the interval from the top of the basal vitrophyre in the Topopah Spring Tuff (389 m) to the Calico Hills Formation (432 m), were analyzed because of earlier results indicating the occurrence of erionite in one sample. The newly analyzed samples confirm the occurrence of an erionite-rich interval (up to 34 percent erionite) from 415 to 419 m depth. Previously studied cores have never contained erionite in such abundance or in this particular interval. This new occurrence of erionite may require a reappraisal of how core and Exploratory Studies Facility samples from this interval are handled and distributed for analysis.

Field work was completed at the UE-25 UZ#16 drill site to characterize the fibrous minerals in dust samples near this drilling operation. Particular attention was paid to erionite, which has not yet been identified in any of the dust samples. Analysis of these samples by x-ray diffraction, scanning electron microscopy, and transmission electron microscopy was largely completed during this period, and a report was in preparation. This study indicates no significant impact of the drilling operation on local eolian dust compositions. The long-term objectives of this study are to (1) provide full characterization of the natural background dusts in the vicinity of Yucca Mountain, (2) determine the impact of Yucca Mountain site

operations on these natural dusts, and (3) determine whether site operations (drilling and excavation) produce dusts representative of the soils and tuffs being disturbed, or whether certain minerals are concentrated in the dust created by these operations.

To provide a baseline comparison to dusts produced by YMP operations at the Yucca Mountain site, YMP scientists continued sampling for hazardous mineral studies. Particulate samplers were set up near the drill rig at USW SD-9, and background dust samples were being studied.

Project scientists significantly improved the precision and accuracy of quantitative measurements of the feldspars and zeolites at Yucca Mountain. This is important because zeolites in particular play an important role in waste retardation, thermal stability, and hydrologic assessments. Chipera and Bish (in prep.) describe an approach to improve quantitative determinations of the abundances of these phases at Yucca Mountain. Modeling of x-ray diffraction characteristics of opal was also under way. Project scientists were examining possible improvements in quantitative determination of this phase and were obtaining a better understanding of mechanisms of transition between opal and other silica minerals.

Analyses of samples from portal excavations at the Exploratory Studies Facility Starter Tunnel site continued. Distributions of calcite, opal, and clays in these samples will provide a comparison with comparable mineral distributions in the Bow Ridge fault, permitting evaluation of mineralogic tracers of fracture versus fault infiltration.

Project scientists improved the precision of their mineralogic models by using closer sample spacing and incorporating additional information to help constrain possible past rises of the water table. Chipera et al. (in prep.) described above for Activity 8.3.1.3.2.1.1, also contains conclusions applicable to this activity. The following findings have important implications for this activity:

1. A closer sample spacing resulted in more continuous data and more precise determination of the boundaries between mineral occurrences with depth. Sampling of UE-25 UZ#16 was performed with a maximum sample spacing of approximately 6 m (20 feet) and an average sample spacing of 4.9 m (16 feet). This sample spacing is much closer than in previous studies in which the average spacing between samples was typically >10 m.

2. Data on the elevation of the glass-to-zeolite transition beneath the potential repository from this study and from future studies can be used to help constrain maximum past water table elevations. Critical localities yet unsampled are within and adjacent to the southern part of the exploration block, but information from these localities will be obtained by future drilling.

Quantitative x-ray diffraction analyses were completed for 128 sorption samples, plus additional "pure" mineral specimens used for sorption studies. Chipera and Bish (1994) describe this work and conclude there are no significant differences in mineralogy between

samples that received various pretreatments before sorption studies. Moreover, earlier results showing high Np sorption by calcretes appear not to be attributable to sepiolite, because pure-mineral tests with sepiolite indicate no enhancement of sorption. This provides a further indication of effective Np sorption by calcite, an effect that may be important in the unsaturated zone at Yucca Mountain, where calcite occurrences appear to be correlated with transmissive fractures.

Preparation of thin sections for microautoradiography, with optical analysis of experimental products, was begun. A review of initial work with thick sections indicated that thin sections were more readily interpreted. Five different tuff types were being studied: devitrified densely-welded Topopah Spring Tuff, devitrified poorly-welded Prow Pass Tuff, vitric nonwelded Calico Hills Tuff, opal-rich zeolitized Calico Hills Tuff, and opal-poor zeolitized Prow Pass Tuff. In addition, examples of calcite-opal associations from an unsaturated-zone fracture were being studied to assess the potential for retardation of radionuclides (particularly Np) by calcite. The first exposures were to Pu solutions, and YMP scientists found some indications of preferred Pu retention by clay-rich clasts within zeolitized tuffs and strong indications of preferred Pu accumulation associated specifically with altered pyroxenes of the devitrified Prow Pass Tuff and with altered oxide minerals in the Topopah Spring Tuff. These studies were continuing.

Calcite separations from fractures were completed for drill core from UE-25 UZ#16. These calcites will be analyzed petrographically and chemically to provide information on their potential role in waste-element retardation and to define zones of recharge into the unsaturated tuffs at Yucca Mountain.

Activity 8.3.1.3.2.1.3. - Fracture mineralogy. The objective of this activity is to determine the distribution of minerals within fractures at Yucca Mountain, within all significant rock masses that might provide transport pathways with some component of fracture flow.

Project mineralogists prepared a guidebook that makes a significant contribution toward ensuring uniform, accurate identification of fracture minerals in the many core studies conducted each year. Carlos and Garcia (in prep.) provide descriptions of all fracture-lining minerals that have been identified at Yucca Mountain. Preliminary copies of the approved text were distributed in June 1994 to YMP staff who are logging core.

Following recent studies, YMP scientists found that the minerals in fractures of the unsaturated zone provide a geochemical environment along transport pathways that is different from that of the rock matrix (these minerals have become the focus of most current sorption studies). Carlos et al. (in prep.) summarizes all available data on fracture-lining minerals in previously drilled core from Yucca Mountain covering data on seven drill cores from five locations. The important conclusions were:

1. Fracture coatings in the Paintbrush Group are much more complex than in the deeper tuffs. The principal zeolites are heulandite, mordenite, and stellerite, in variable abundances. These fracture-lining zeolites occur in both devitrified and

zeolitized intervals. Multiple chemical compositions in single heulandite deposits indicate several episodes of deposition. The principal Mn-oxides in the Paintbrush Group are rancieite and lithiophorite.

2. Below the Paintbrush Group, fracture-lining zeolites generally correspond to zeolitic alteration in the tuffs (clinoptilolite, mordenite and, in the deeper tuffs, analcime). Fracture coatings in the devitrified tuffs are principally calcite, quartz, and Mn-oxides of the cryptomelane/hollandite family. Both the calcite and the Mn-oxides may be important in retarding radionuclide migration.

3. Future studies of fracture coatings in the Paintbrush Group will concentrate on mineral stability under thermal loading and factors that control deposition or indicate recent flow pathways. Studies of fracture minerals in deeper tuffs will concentrate on distributions of calcite and oxide minerals that may have a special role in retarding radionuclide migration.

Forecast: The chemistry of minerals lining faults and selected fractures and bulk-rock samples in the Exploratory Studies Facility will be identified and determined. Core from the Surface-Based Testing program and, as appropriate, samples from the Exploratory Studies Facility will be used to study minerals present at trace or minor levels that may influence or control the sorption behavior of the rocks above and below the potential repository horizon. Natural background levels of airborne mordenite and other potentially hazardous minerals at Yucca Mountain will be determined before surface-disturbing activities associated with the Exploratory Studies Facility begin at the site. The mineralogy of airborne dust in the vicinity of drilling operations and at the Sample Management Facility will be characterized. Participation will take place in studies of the potential health risks associated with the inhalation of fibrous minerals by YMP workers during drilling, Sample Management Facility, and Exploratory Studies Facility operations. The mineralogy and chemistry of calcite in fractures at Yucca Mountain will be examined to determine the origin of calcite-depositing fluids and to identify paleo-transport pathways for these fluids. X-ray powder diffraction, x-ray fluorescence, electron microscopy, and petrography will be used to examine core from the Surface-Based Testing program to determine the mineralogy of units above and below the potential repository horizon. The chemistry of fracture-lining minerals in drill core from Yucca Mountain will be identified and determined. Distribution of fracture minerals will be determined as a function of stratigraphic position, depth from surface, welding and crystallization of wall rocks, and position with respect to present-day and paleo-water tables. Lateral variability of fracture-lining minerals will be determined by comparing these minerals between drillholes.

3.2.3 Study 8.3.1.3.2.2 - History of Mineralogic and Geochemical Alteration of Yucca Mountain

The objectives of this study are to determine the timing, temperatures, and hydrologic conditions of past alteration at Yucca Mountain; and to study experimentally the dehydration

of smectite, zeolite, and glass. Processes range from deep-seated past hydrothermal alteration to shallow mineral deposition along fractures and faults.

Activity 8.3.1.3.2.2.1 - History of mineralogic and geochemical alteration of Yucca Mountain. The objectives of this study are to constrain the timing of deep-seated alteration of a hydrothermal and epigenetic nature; to estimate the long-term thermal stabilities of important sorptive phases, such as clinoptilolite, and of the silica polymorphs that can influence water composition, precipitation, and the stabilities of other silicate minerals.

Hydrogenic Deposit (Calcite-Silica) Studies

The potential for episodic surface discharge of ground water from depth, which could result in a release of radionuclides, has received considerable publicity as a site suitability concern and several scientific panels have examined the merits of the controversy. Project scientists defined two complementary approaches to evaluate this problem. The first concentrated on the laminated calcite-silica deposits observed in fault zones, comparing them to soil carbonates and spring deposits. The second identified breccia zones and surficial hydrothermal deposits, searching for evidence that any could be of Quaternary age or related to ongoing active processes.

The final report on laminated calcite-silica deposits by Vaniman et al. (in prep.) contains detailed geochemical comparisons of laminated deposits in the Bow Ridge fault with adjacent pedogenic calcretes, overlying soils, and known spring and seep deposits in the region. The data identify mineralogic and chemical affinities among the fault deposits, adjacent bedrock, overlying soils, and a possible eolian contribution. A report covering the final research on hydrothermal deposits by Levy (in prep.[a]) concluded that none of the hydrothermal deposits analyzed were of Quaternary age. Data from both studies were incorporated into a report expressing the author's confidence that ground water upwelling is not expected at Yucca Mountain (Levy, in prep.[b]). This research is important for a greater understanding of ground water infiltration into the unsaturated zone and the origins of subsurface calcite, a potentially important mineral for retardation of some transuranic elements. Project researchers have also identified analog sites for studying hydrothermal alteration similar to the effects of a potential repository.

Potassium-argon studies of zeolites and other secondary minerals are important to confirm the timing of zeolitic alteration at Yucca Mountain. Results obtained from potassium-argon studies of Yucca Mountain clinoptilolites show a consistent pattern of older apparent ages, approaching the ages of the host tuffs, in samples from below the static water level and younger ages in samples from the unsaturated zone. Within the unsaturated zone, apparent ages become younger with decreasing depth. A major effort was devoted to understanding the processes responsible for the young apparent ages that are at odds with geologic and petrologic age data. Preliminary experimental results suggest that unsaturated conditions may accelerate the rate of argon loss from the mineral by ion-exchange or dehydration, leading to apparent ages that are too young. WoldeGabriel (in prep.) describes apparent ages as young as 2 Ma obtained at Yucca Mountain that could have important implications for the magnitude of recent water table changes.

Studies of zeolites and other secondary minerals from tuffs deposited in alkali, saline lakes in the region around Yucca Mountain were undertaken to gain a better idea of the variability of zeolite potassium-argon apparent ages compared to the ages determined for other minerals. WoldeGabriel et al. (1994) conclude that lake deposits contain a greater abundance and variety of dateable secondary minerals than Yucca Mountain tuffs. The results are similar to the Yucca Mountain data in the sense that most clinoptilolites seem to have lowered potassium-argon apparent ages.

To better understand chemical transport during zeolitization, YMP researchers undertook various paleohydrology studies. Data collection was completed, and two papers were prepared. Levy and Valentine (1994) identified a useful "self-analog" predictor of fluid-rock interactions within the thermal regime imposed by a potential repository; the tuff identified has the advantages of representative rock types and appropriate spatial distribution of lithologic features. The cooling history of the tuff spanned the temperature range for any proposed thermal load, and the unsaturated-zone hydrologic conditions of the natural alteration would have been similar to existing conditions. A site at northeastern Yucca Mountain, with a prominent vertical fracture zone, will be used for analog studies. The cooling of the tuff and the movement of water in the fracture zone and adjacent matrix will be modeled using the YMP computer code FEHMN, developed under Study 8.3.1.3.7.1.

Levy (in prep.[c]) describes three types of altered rock from Yucca Mountain drillholes that can be used to indicate the volume of secondary minerals expected from dissolution of Topopah Spring vitrophyre, patterns of zeolitization in nonwelded Topopah Spring tuff, and total element transport in bedded Crater Flat tuff. This work developed techniques to help predict hydrologic properties of the vitric-zeolitic transition between drillholes.

To determine how many alteration or mineral deposition episodes are represented by the numerous quartz, chalcedony, and opal occurrences at Yucca Mountain, secondary-silica deposits were identified, separated, and x-rayed for possible stable isotope studies by the USGS. The results will be applied to paleohydrology studies to help identify former or existing fast fluid flow paths through Yucca Mountain.

Activity 8.3.1.3.2.2.2 - Smectite, zeolite, manganese minerals, glass dehydration, and transformation. The objectives of this activity are to determine how minerals and glasses important in the rocks at Yucca Mountain will dehydrate and transform under anticipated thermal loads; and to investigate the ability of zeolites and smectites to rehydrate after the peak in temperature.

Project researchers concentrated on collecting the basic thermogravimetric data needed to predict the behavior of hydrous minerals in a repository thermal environment. These data will be used to derive mathematical expressions that will incorporated into numerical models of repository thermal effects. Data collection in two areas was completed, and two papers on this subject were published.

In the first paper (Carey and Bish, 1994) a model of the hydration energetics in zeolite, developed using new data collected on Na, K, Ca, and Mg end-member clinoptilolite from

thermogravimetric equilibration studies, was presented. This paper describes a model in which the adsorption of water by zeolites has two distinct energetic contributions: sorption of water molecules on framework oxygens and other water molecules and solvation of the cage cations. The model explains the relatively small differences in enthalpies of hydration among differing cation end members as a consequence of the changing ratio of cation to total water content.

In the second publication, YMP scientists (Chipera et al., 1994) described their results with respect to smectite expansion at high relative humidity. They found that relative humidity varies between 0 and 3 water layers and occurs in distinct steps; stepwise contraction during dehydration is more sharply defined and occurs at lower relative humidity than during hydration. They also found that water gain/loss in the clays does not occur in the same distinctive steps as the structural expansion/contraction but occurs in a more linear manner with relative humidity. Water abundance also displays hysteretic behavior during hydration/dehydration in that the smectites retain more water during dehydration. Homoionic Na-, K-, and Ca-exchanged end members plus unexchanged samples were analyzed under controlled relative humidity going from dry to water-saturated and back to dry conditions. X-ray powder diffraction was used to determine the expansion/contraction behavior of the clay structure, and isothermal thermogravimetric analysis was used to determine smectite water content as a function of relative humidity.

A 22-month test phase of long-term steam-heating experiments was completed. Project scientists found that the reaction vessels did not hold a steam atmosphere for very long, and all of the samples dried out at some time. The starting materials included powdered samples of Yucca Mountain devitrified tuff, vitric nonwelded tuff, vitrophyre, smectite-rich altered tuff, zeolitic altered nonwelded tuff, Na-bentonite, Ca-smectite, opal-CT, and two standard clinoptilolites. The reaction vessels were maintained in ovens at 100° and 200°C and initial 2:1 water-rock ratios. X-ray diffraction analysis of the charges showed no mineralogic changes. Future long-term steam-heating experiments will be conducted at LLNL in vessels capable of holding a steam atmosphere.

Forecast: Existing alteration effects at Yucca Mountain will be examined to determine the approximate timing of alteration and the conditions under which the rocks were altered. An experimental approach will be used to determine the thermodynamics of water in zeolites and clays at Yucca Mountain and to determine the rates in which these minerals will dehydrate and rehydrate in a repository environment. Potassium-argon dating methods will be used to place bounds on the timing of mineral formation and alteration at Yucca Mountain. Samples from drillholes, Exploratory Studies Facility, outcrops, and trenches will be examined to determine the relationships between mineralogic alteration history and hydrologic history.

3.2.4 Study 8.3.1.3.3.1 - Natural Analog of Hydrothermal Systems in Tuff

The objectives of the study are to improve the reliability of long-term predictions regarding hydro-thermal rock alteration in devitrified welded ash-flow tuff; to test the

capabilities of the EQ3/6 geochemical code through modeling of alteration mineral assemblages in natural systems; and to provide a better understanding of the origin of alteration mineral assemblages currently found in Yucca Mountain.

As a part of a work scope consolidation effort for study plans, this study plan will not be written. Much of the work is a compilation effort to select analog site(s) combined with testing and/or calibration of EQ3/6. This study is not site characterization work, would not substitute for site-specific data, and has utility only in reducing uncertainties in EQ3/6 applications. Some of the work overlaps with work being planned in two other studies, 8.3.4.2.4.1 (Characterization of Chemical and Mineralogical Changes in the Post Emplacement Environment) and 8.3.1.20.1.1 (Altered Zone Characterization). The study plans were being revised, and the Site Design and Test Requirements document will then be changed accordingly.

Forecast: The study plans will be revised, and the Site Design and Test Requirements document will be revised.

3.2.5 Study 8.3.1.3.3.2 - Kinetics and Thermodynamics of Mineral Evolution

The objectives of this study are to investigate the kinetics of glass and silica polymorph transitions and their relationship to aqueous silica activity; and to provide thermodynamic data for clinoptilolite/heulandite and albite and analcime.

Project scientists measured the solubility of Na-clinoptilolite, and a solubility product was calculated for clinoptilolite at temperatures from 125° - 265°C. From these values, the reaction enthalpy and entropy were calculated, and they agreed very well with literature calorimetric values. These data are important because they allow proper formulation of future kinetic experiments on clinoptilolite that should yield information to predict the behavior of clinoptilolite in a repository environment as a function of time and temperature. For example, the experiments will evaluate the possibility that clinoptilolite will become unstable in solutions with low silica concentrations, such as those saturated with respect to quartz. Such predictions are not now possible.

Project scientists conducted analcime solubility experiments, which yielded results that will allow the formulation of next year's kinetic experiments. These kinetic data, coupled with kinetic data for clinoptilolite, should eventually allow predictions of the extent of the clinoptilolite-to-analcime reaction at Yucca Mountain. Without the analcime data, it will not be possible to provide an estimate of the conditions under which clinoptilolite may transform to analcime under the influence of the repository thermal load, a possibility proposed in the literature since the early 1980s.

Experimental evaluation of the dissolution rate of analcime yielded a rate significantly faster than that of clinoptilolite. When more rate data are available, these data will be combined with rate data on clinoptilolite to predict the effects of time and temperature on analcime-clinoptilolite equilibrium.

Data collection on the rates of dissolution and precipitation of cristobalite from 150° - 300°C was completed, and a letter report was prepared (Renders et al., in prep.). The activation energy of dissolution is 68.9 +/- 11 kJ/mol, and the activation energy of precipitation was found to be 52.9+/- 10 kJ/mol, in agreement with activation energies for other silica polymorphs. This agreement is consistent with the assumption that all silica polymorphs precipitate by the same rate-limiting elementary reaction. The results of this work show that cristobalite may precipitate from hydrothermal solutions if the concentration of $Si(OH)_4$ exceeds cristobalite saturation but is less than amorphous silica saturation, only if there are cristobalite nuclei present. In other words, the presence of cristobalite nuclei catalyzes the metastable precipitation of hydrothermal cristobalite.

Forecast: The rates of dissolution, precipitation, and reaction of clinoptilolite, mordenite, analcime, and the silica phases present at Yucca Mountain will be experimentally determined. Experiments will be conducted from 50° - 250°C in flow-through hydrothermal systems to bracket the temperatures expected in a repository environment. Data will be obtained as a function of time, temperature, and water and mineral composition. Data will also be obtained from the literature for phases such as quartz.

Using various experimental techniques, the best experimental procedures for use in the Kinetics of Mineral Dissolution and Reaction Activity will be formulated.

A conceptual model of natural and repository-induced mineral evolution at Yucca Mountain will be produced. The potential geochemical and mineralogical effects of thermal loading and the possible impacts on radionuclide containment and rock properties will be summarized. This work will culminate in an overall model of the anticipated behavior of the secondary phases at Yucca Mountain as a function of time, temperature, water and mineral composition, and water-vapor pressure.

3.2.6 Study 8.3.1.3.3.3 - Conceptual Model of Mineral Evolution

This objective of this study is to explain observed distributions of minerals in Yucca Mountain. Emphasis will be placed on the evolution of frameworking silicates (feldspars, zeolites, and silica polymorphs). The model will address the general chemical evolution off vitric tuffs. This model will also be used to predict future mineral evolution in the mountain due to both natural processes and as a result of a repository emplacement.

This study has been combined with Study 8.3.1.3.3.2. A discussion and status is included in Section 3.2.5.

3.2.7 Study 8.3.1.3.4.1 - Batch Sorption Studies

The objective of this study is to obtain sorption coefficients for key radionuclides as a function of the parameters. These studies will use statistical analysis to evaluate the experimental results and will provide the data base for the development of models to allow

prediction of sorption coefficients under conditions not directly addressed by the experimental program.

This study is being revised to incorporate Study 8.3.1.3.4.3, Development of Sorption Models. When the revised study plan is completed, this discussion will address the development of sorption models currently contained in Section 3.2.9.

Activity 8.3.1.3.4.1.1 - Batch sorption measurements as a function of solid phase composition. The objective of this activity is to determine sorption coefficients for radionuclides on tuffs of the Calico Hills zeolitic and vitric units, on devitrified tuffs, and on pure minerals representative of the minerals present in the rock and fractures of the repository block.

The sorption data generated by YMP geochemists for performance assessment calculations were published (Wilson et al., 1994). Project geochemists reviewed these results and reached the following conclusions: (1) retardation of radionuclides by sorption may be important for meeting radionuclide release limits, depending on the time period of the new regulatory criteria; (2) there are several voids in the sorption data base (especially dealing with the tuffs in the vitric Calico Hills) that should be addressed before the next performance assessment cycle; (3) the radionuclides of major concern in terms of their sorption properties are Np, U, and Se; and (4) the release of Pu may become a problem if colloidal Pu species are formed. The sorption research continued to focus on addressing these issues.

Project geochemists compiled a Np-sorption data base, which includes Np-sorption data as a function of stratigraphic unit and ground water composition at Yucca Mountain. The data base was distributed to other YMP scientists performing modeling studies (in Study 8.3.1.3.7.1, Retardation Sensitivity Analysis). The scientist's major conclusions following review of this data base were: (1) Np sorption onto vitric and devitrified tuffs is insignificant, (2) The sorption of Np onto zeolitic tuffs is on the order of 2–5 ml/g in UE-25 J#13 water and zero in UE-25 p#1 water, and (3) Np sorbs strongly to oxide minerals and calcite. A report summarizing this work is in preparation (Triay, in prep.) This data base will be submitted to the YMP data base (GENISES) during the next reporting period.

As a result of a concern expressed by the NWTRB that organic coatings in the natural system would change the sorption behavior of tuffs, YMP scientists conducted a study to determine the effect of naturally occurring organic materials on the sorption of Np onto oxides and tuff surfaces. Data collection was completed for this study, and a paper was prepared (Kung and Triay, in prep.). The sorbers used were synthetic goethite, boehmite, amorphous silicon oxide, and a crushed tuff material from Yucca Mountain. An amino acid, 3-(3,4 dihydroxypheny)-DL-alanine (DOPA), and an aquatic-originated fulvic material, Nordic aquatic fulvic acid (NAFA), were used as model organic chemicals. Findings from this study indicated that these coatings on tuff or iron and aluminum oxides did not influence Np sorption. It appears that Np is bound weakly to organic material, and the above-mentioned organic chemicals have little effect on Np sorption for all the sorbers tested.

Activity 8.3.1.3.4.1.2 - Sorption as a function of sorbing element concentrations (isotherms). The objective of this activity is to characterize the dependence of sorption coefficients upon the concentration of the element being sorbed by developing isotherms for the radionuclide. This activity will develop isotherms for the radionuclides to be tested. These isotherm data will be incorporated into the sorption data base for use in determining element concentration levels at which precipitation begins to contribute to the measured sorption ratio, and in modeling sorption to predict retardation along flow paths.

Data collection on the sorption of Np onto calcite as a function of concentration in UE-25 J#13 and UE-25 p#1 water was completed. These studies indicated that calcite can sorb Np strongly. This is an extremely important finding because if calcite is found in fractures at Yucca Mountain, significant Np retardation can occur by sorption during fracture flow. These results will be summarized along with the transport through fractured column results in a report (Triay, in prep.).

Project scientists studied Se, U(VI), and Pu(V) as a function of radionuclide concentration using tuffs and pure minerals in ground waters from UE25 J#13, UE-25 p#1, and synthetic ground waters with varying amounts of carbonate and a report (Triay, in prep.) describing this work was in preparation. The results of these experiments will provide needed sorption data on these radionuclides to performance assessment.

Activity 8.3.1.3.4.1.3 - Sorption as a function of ground water composition. The objective of this activity is to measure sorption coefficients as a function of ground-water compositions anticipated along potential travel paths. These data will contribute to the sorption data base and support the sorption model development and performance assessment calculations.

To predict the influence of ground-water composition on the sorption data used in performance assessment, YMP scientists were investigating the feasibility of using surface complexation models to fit radionuclide sorption data. Interpretation of these results will be based on two studies (Kohler et al., in prep. [a]) and (Kohler et al., in prep. [b]) completed and approved during this reporting period. These reports cover, respectively, uranyl interactions with goethite and Np sorption on hematite in the presence of carbonates and EDTA. Project scientists also designed and initiated surface complexation experiments of U onto devitrified tuffs. The results will be described by Leckie et al. (in prep.).

Activity 8.3.1.3.4.1.4 - Sorption on particulates and colloids. The objective of this activity is to determine if sorption of important radionuclides occurs on particulates or colloids that may be present in ground waters along potential transport pathways. Batch techniques, modified to accommodate the much smaller sample sizes, will be used to measure sorption. If any sorption is measured, the use of sorption coefficients alone may not accurately predict the transport of sorbed radionuclides.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.3.4.1.5 - Statistical analysis of sorption data. The objective of this activity is to produce statistical correlations and error estimates. Various statistical approaches will be used on the sorption data to determine those variables (e.g., mineralogy, ground-water composition, and atmosphere) having the most profound effect on the sorption coefficients; to predict sorption coefficients as a function of mineralogy and, perhaps, ground-water composition; to estimate errors associated with predicted sorption coefficients; and to identify gaps in the experimental data.

No progress during the reporting period; this was an out-year activity.

Forecast: Whether sorption of Pu occurs on particulates or colloids that may be present in ground waters and along potential transport pathways will be determined. Experimental techniques will be developed and optimized for batch sorption experiments using whole rock material obtained by drilling and from the Exploratory Studies Facility at Yucca Mountain. Analytical artifacts and uncertainties will be resolved. Detailed procedures will be prepared and revised as necessary. Studies of sorption of Pu, Np, U, and Se onto tuff and iron oxides will be conducted. Actinide Sorption Workshop will be conducted. Experiments will be conducted to obtain data on the dependence of K_ds on radionuclide concentration in UE-25 J#13 and UE-25 p#1 waters. The focus will be on key radionuclides (Pu and Np) as developed from the sorption strategy and specific ground-water compositions. Sorption coefficients of Pu and Np as a function of ground-water compositions anticipated will be measured along potential travel paths. Data will be contributed to sorption data base and will be used to support sorption model development. Sorption experiments on pure separates of the minerals found in Yucca Mountain tuffs involving various solution compositions and the important radionuclides will be performed; the data resulting will be used to extrapolate whole-rock K_d data. The effects of organics on Pu sorption will be investigated.

3.2.8 Study 8.3.1.3.4.2 - Biological Sorption and Transport

The objectives of this study are to determine what effects microorganisms have on the movement of radioactive waste (i.e., effects on sorption) and to determine if microbial activities play a role significant enough to be included in performance calculation for Yucca Mountain; to identify the quantity, location, and characteristics of past and future organic materials used at the site and their susceptibility to microbiological degradation; and to determine the effect that these microorganisms will have on the movement of actinides through analysis of their effect on ground-water quality, colloid formation, effect on solubility, or by direct sorption of the actinides.

No progress during the reporting period; this was an unfunded study.

Forecast: This study is funded for FY 1995. A report will be written describing sampling procedures and microbiologic analyses of Exploratory Studies Facility samples. Rock will be collected behind the tunnel boring machine to determine ambient microbe

populations at Yucca Mountain. Once these populations are characterized, work will commence describing the importance of these microbes to radionuclide transport.

3.2.9 Study 8.3.1.3.4.3 - Development of Sorption Models

The objectives of this study are to model the sorption experiments on rocks and minerals representing the proposed repository block and to derive a capability to predict sorption coefficients for key radionuclides under water-rock conditions not included within the experimental program.

This study is being combined with Study 8.3.1.3.4.1. When the revised study plan is completed, the discussion of this study will be included in Section 3.2.7.

Project scientists continued to study the surface characteristics of natural mineral assemblages to contribute to a further understanding of the mechanism behind the sorption of Np onto tuff; this sorption, which is 1 to 2 orders of magnitude lower than that predicted from the pure mineral K_ds, must be more thoroughly explained. The measured Np sorption coefficients onto iron mineral separates taken from Yucca Mountain tuff are in better agreement and can be used for performance assessment; however, it will be difficult to defend the use of those K_ds without an understanding of the mechanism behind those numbers and the reasons for the discrepancy between Yucca Mountain tuff iron oxides and pure minerals.

To define the differences (and understand the discrepancies) between Np sorption onto Yucca Mountain tuff iron oxides and onto pure minerals, YMP scientists have continued to refine their atomic force microscopy studies of maghemite minerals. To ensure that the surface structures were not "tip artifacts" or otherwise erroneous, the surfaces were reimaged using scanning tunneling microscopy, which uses a totally different physical method for producing images. Project scientists were able to image both the multifaceted and planar regions found previously with atomic force microscopy on the maghemite separates, and the scanning tunneling microscopy images showed the same structures as the previous atomic force microscopy images. A third surface with a billowy structure was observed only with atomic force microscopy, and was being further investigated (Hawley and Rogers, 1994).

To further understand the correlation between the quantity of calcite in a tuff sample and Np sorption, YMP scientists set up experiments using atomic force microscopy to study whether thin coatings of calcite exist on mineral surfaces or as fracture linings.

Forecast: Fundamental data on the impact of surface composition on sorption will be obtained. Experiments will be conducted using advanced surface science techniques to determine the composition and coverage of sorbing surfaces in Yucca Mountain tuffs. Important reactions of these coatings that might result from a change in water composition or pH also will be studied as they relate to changes in measured sorption density. The final result will be an improved understanding of the mechanism of surface adsorption in Yucca Mountain and a better model for use in performance assessment.

3.2.10 Study 8.3.1.3.5.1 - Dissolved Species Concentration Limits

The objective of this study is to provide solubility or concentration limits for dissolved species of important waste elements under conditions that are characteristic of the repository and along flow paths toward the accessible environment.

Activity 8.3.1.3.5.1.1 - Solubility measurements. The objective of this activity is to specify the conditions under which solubility experiments will be carried out and then measure solubilities or concentration limits of important waste elements under these conditions.

Data collection was completed on a comparison of solubilities and redox characterizations from oversaturation and undersaturation experiments on Np, Pu, and Am in UE-25 p#1 well water. Hobart et al. (in prep.[a]) describes this work and confirms that oversaturation and undersaturation radionuclide solubility experiments approached the same bulk solubility value, indicating that equilibrium values were reached. These relatively short-term oversaturation experiments may be used to predict long-term solubilities.

By comparing the simple system of a neutral electrolyte with carbonate, Hobart et al. (in. prep.[b]) were able to show that carbonate is one of the main influences in radionuclide solubility measurements.

Activity 8.3.1.3.5.1.2 - Speciation Measurements. The objective of this activity is to identify important aqueous species of waste elements under conditions described in Activity 8.3.1.3.5.1.1 and determine their formation constants.

To clearly define solubility parameters and bridge gaps in the data acquired from recent bulk solubility experiments, YMP scientists initiated experiments to thermodynamically characterize radionuclide speciation. These experiments produce thermodynamic constants required for reliable solubility modeling. The experimental results indicated that hydrolysis of NpO_2^+ will not occur in any expected far-field water environment, as virtually no NpO_2OH exists at pH >9. However, the researchers believe that higher temperatures and higher pHs are possible in the near-field (cement waters typically are at pH=10), and extension of these measurements to higher temperatures (to 90°C) are desirable. An important implication of these findings is that carbonate complexation data should be reinterpreted in light of the weak hydrolysis constant found and then extended to higher temperatures. Past room temperature studies and the current EQ 3/6 data base have assumed a larger hydrolysis constant than we are finding. Proper interpretation of the carbonate work requires hydrolysis data as a prerequisite. A letter report detailing this work was in preparation (Janecky and Duffy, in prep.).

In conjunction with Study 8.3.1.3.4.1, near infrared absorption spectra for saturated Np solutions in carbonate solutions equivalent to UE-25 J#13 and UE-25 p#1 waters were collected. These spectra confirmed an NpO_2^+ / $NpO_2(CO_3)^-$ mixture for the former solution and essentially only $NpO_2(CO_3)^-$ for the latter solution. This information was compared with previous extended absorption fine structure experiments, in which significant differences in

the fine structure spectra were not seen. Solution Samples of Np(V) carbonates stabilized using the tetramethyl-ammonium carbonate were prepared and shipped to YMP scientists at Stanford University for extended absorption fine structure experiments.

Because YMP scientists observed that Np(V) carbonate solubility is greatly increased in the absence of alkali metal cations (e.g., Na^+ and K^+), they have been able to study Np(V) carbonate speciation using optical spectroscopy at concentrations high enough to avoid the large overtone bands from water in the spectra (tetramethylammonium nitrate was used as a supporting electrolyte). Solutions of Np(V) in tetramethylammonium carbonate (in the presence of tetramethylammonium nitrate) were examined and found to be stable and soluble. Because the $[CO_3^{2-}]$:$[HCO_3^-]$ ratio increased by a factor of 2.5 from 25° - 80°C, this implied that this equilibrium constant is actually getting weaker at higher temperatures. The temperature dependence of Np hydrolysis and carbonate complexation, as well as implications for solubility modeling, will be reported by Tait et al. (in prep.).

Project scientists also performed spectroscopic determinations of oxidation state distribution on a Pu sample consisting of 2 ml of 48 nM Pu at pH = 6. Since Pu(IV) and Pu(VI) have strong, distinct absorption bands, their strategy was to look for them. Because of the low concentrations of plutonium involved, the sensitivity of photoacoustic spectroscopy was required to obtain the data directly. By comparing their samples with known samples, they could determine that the percentage of Pu(IV) in the sample was <30 percent, while that of Pu(VI) was <50 percent. The remainder, assumed to be Pu(V), was therefore at least 20 percent, and probably significantly higher. The extremely low Pu concentration of this particular sample (~50 nM) allowed for only a partial validation of the indirect solvent extraction technique.

Because of various health and safety compliance problems, NMR experiments were reduced in scope this period; however, YMP scientists did examine oxygen-17 labeled samples of Np(V), Np(VI), Pu(V), and Pu(VI) on a 500 MHz instrument. The original observation of the Np(VI) resonance at 2899 ppm was reproduced, as well as the Pu(V) resonance at 2400 ppm. Project scientists were unable to locate the resonances for Np(V) and Pu(VI), but these are predicted to have the greatest paramagnetic shifts due to the large anisotropy of the unpaired electrons in these systems. These experiments are important because we have observed that the oxygen-17 nucleus bound directly to a paramagnetic actinide center is extremely sensitive to subtle changes in coordination environment. These changes are expected to help map out the stability fields of Np(V) carbonate complexes in order to provide the necessary anchor points for fitting spectrophotometric data already acquired.

A survey report on the literature data base of radiocolloids was in preparation. Plutonium is the focus of this letter report, but it is possible that other actinide-colloids will be included in this report.

Activity 8.3.1.3.5.1.3 - Solubility Modeling. The objective of this activity is to develop the thermodynamic models and data needed to calculate waste element solubilities over the range of conditions expected at the site.

Project scientists modeled Np and Pu solubility using information from the GEMBOCHS data base and compared this to recent experimental results on the solubility of Np in UE-25 J#13 water (Nitsche et al., 1992). QA-approved EQ3/6 software was used. Interestingly, the modeling predicted that Np would dissolve much more than was actually observed. Certainly part of this discrepancy lies in problems with the Np data base. These modeling studies indicate that the hydrolysis and carbonate complexation values should be adjusted to values found in the speciation work described above. Additionally, the Na^+ concentrations in the actual experiments were increased by pH adjustments, and the extra sodium ions might have had an effect on the Np concentration through the formation of the so-called "double salt" precipitates. The first step in reconciling the discrepancies lies in continued modeling with better data base numbers that are tailored to Np, and this effort was being pursued. A letter report describing these results was in preparation.

Forecast: Thermodynamic modeling of existing solubility and speciation data for Np and Pu will be performed. Scoping calculations to test sensitivity of solubility data to solution conditions outside the bounds used in laboratory experiments will be initiated. Solubility measurements for Np and Pu will be performed in UE-25 J#13 well water at three pH values and three temperatures from undersaturation conditions. The solubility of other radionuclides of potential importance to the repository from oversaturation and/or undersaturation as a function of ground water Eh, pH, and temperature will be determined. Candidate radionuclides include Tc and Se. This work involves preparation and characterization of solid compounds of the listed actinides, followed by dissolution to steady state concentration. Speciation and equilibrium stability constants of radionuclides will be determined by a combination of techniques, including photoacoustic, nuclear magnetic resonance, Raman, and luminescence measurements. Experiments will be conducted at both higher concentrations and at concentrations that are typical of radionuclides at near-neutral water conditions. Comparisons between both concentration regions will be conducted. Data from this study is needed to allow thermodynamically defensible solubility and sorption calculations to be performed by performance assessment at any general water composition. Pu and Tc will be studied. A computer code data base for making model calculations of radionuclide speciation in solution will be identified, acquired, and modified. Both equilibrium and nonequilibrium (i.e., kinetic) phenomena will be incorporated. A data base will be identified and supplemented with data from solubility and speciation experiments conducted in this study.

3.2.11 Study 8.3.1.3.5.2 - Colloid Behavior

The objective of this study is to determine the stability of waste element colloids under expected site-specific conditions that might be encountered at the repository or along flow paths toward the accessible environment.

Activity 8.3.1.3.5.2.1 - Colloid formation characterization and stability. The objective of this activity is to determine formation and stability of waste element colloids.

A letter report on the literature data base of radiocolloids titled "Letter Report on the Status of Pu (IV) Colloid" was prepared. Plutonium, one of the most long-lived and dangerous radionuclides that will be present in the potential repository, was the focus of this letter report.

Activity 8.3.1.3.5.2.2 - Colloid modeling. The objective of this activity is to develop models and parameters to calculate natural colloid concentrations and stability and to describe the disposition of the waste element species as the colloids break up.

No progress during the reporting period; this was an unfunded activity.

Forecast: Studies will be performed of the formulation, characterization, and stability of Pu(IV) colloids under solution chemical conditions relevant to the repository. Emphasis in Stage 2 will be on determination of physical properties including bulk charge and density.

3.2.12 Study 8.3.1.3.6.1 - Dynamic Transport Column Experiments

The objective of this study is to measure the breakthrough or elution curve for tracers through tuff columns.

Activity 8.3.1.3.6.1.1 - Crushed tuff column experiments. The objective of this activity is to measure the rate of movement through crushed tuff columns of radionuclides relative to tritiated water and other well-defined chemical species or colloids.

The role of sorption in the retardation of radionuclides was interpreted using sorption distribution coefficients (K_ds) in performance assessment calculations (Wilson et al., 1994). The K_ds used were obtained from the results of batch sorption experiments, which involved equilibrating a solution containing radionuclides in ground water with crushed tuff. It is necessary to validate a subset of the sorption distribution coefficients obtained from batch sorption experiments under flowing conditions. To this end, YMP scientists performed crushed-rock column experiments to study the retardation of Np(V) and Pu(V) in devitrified, vitric, and zeolitic tuffs in ground waters from UE-25 J#13 and UE-25 p#1. These crushed-rock column experiments were performed as a function of flow velocity, and the results indicated that batch sorption distribution coefficients conservatively predict radionuclide transport through Yucca Mountain tuffs. Therefore, validated sorption data can be used for performance assessment calculations.

Activity 8.3.1.3.6.1.2 - Mass transfer kinetics. The objective of this activity is to determine the elution rate of radionuclides as a function of water velocity for crushed tuff columns (homogeneous system), solid rock columns (heterogeneous system), and for pure mineral samples.

Validation of the batch sorption distribution coefficients for Np(V) in UE-25 J#13 and UE-25 p#1 using solid-tuff columns made of zeolitic tuffs was undertaken during this reporting period. These experiments were performed as a function of flow velocity to assess

the kinetic effects on the migration of Np. The results indicated that zeolitic tuffs can significantly retard Np migration through Yucca Mountain tuffs.

Activity 8.3.1.3.6.1.3 - Unsaturated tuff columns. The objective of this activity is to measure the relative migration rate of radionuclides through partially unsaturated rock columns.

Conca and Triay (1994) completed a laboratory study of Se transport through unsaturated tuff columns and began a study of uranium through unsaturated columns. These experiments (performed with water from UE-25 J#13) were designed to verify whether batch sorption coefficients can describe radionuclide transport through unsaturated tuff. The results indicate that (1) Se exits as an anion in UE-25 J#13 water, (2) Yucca Mountain tuffs can provide relatively little retardation for Se, and (3) Se migration through tuffs can be predicted using batch sorption distribution coefficients. Data collection on the validity of using batch sorption K_ds to describe radionuclide transport of uranium under various degrees of saturation was in progress.

Activity 8.3.1.3.6.1.4 - Fractured tuff column studies. The objectives of this activity are to measure the transport and diffusion of radionuclides through naturally fracture tuff; and to examine the movement of tracers through naturally fractured Yucca Mountain cores to test the transport models.

Using autoradiography, YMP scientists focused on characterizing the radionuclide retardation that can be expected from radionuclide sorption onto minerals coating the fractures in fractured-tuff column experiments. These experiments involved generating thin sections of Yucca Mountain tuffs, exposing the tuffs to radionuclides in ground water solutions, adhering a thin photographic emulsion to the section, exposing the emulsion, developing the emulsion to expose the alpha-particle tracks, and correlating the minerals in the tuff thin sections with developed tracks denoting the sorption of actinides onto the tuff minerals. During this reporting period, the thin sections were loaded with radionuclides and autoradiography was used to develop tracks onto the sorbing minerals. The identity of the sorbing minerals in the tuffs was being determined. A paper on this subject was being prepared.

Activity 8.3.1.3.6.1.5 - Filtration. The objective of this activity is to quantify the filtration of colloids and particulates by the tuff as a function of particle or pore size using solid tuff cores and fractured cores.

Project scientists collected water from UE-25 J#13 and analyzed it for colloid concentration using particle-counting light-scattering techniques. These experiments were performed in collaboration with Professor Claude Degueldre of the Swiss National Cooperative Society for the Storage of Radioactive Wastes. The scientists found that the colloid concentration in UE-25 J#13 water is 10^6 particles per ml, and they concluded because of this small colloid loading, facilitation of radionuclide transport by colloids at Yucca Mountain will be minimal. These conclusions were supported by the work presented at the July 1994 NWTRB meeting that summarized the efforts of the European community in the colloid area.

Forecast: Column experiments will be conducted using crushed material to verify the results of batch sorption measurements under flowing conditions. Columns are packed, tracers are injected into the columns and tritiated water is used to determine the column parameters. Crushed material will include devitrified tuff, vitric tuff, and zeolitic tuff. Work on Np and Pu will be completed and studies on U and Se will be initiated. Experiments will be conducted on the transport of radionuclides (Np, U, and Se) through intact tuff columns under varying degrees of saturation. Experiments will be conducted on fractured-tuff columns to investigate the transport of radionuclides (Np, Se, and Cs) with transverse matrix diffusion and channeled flow in fractures. Tuff samples containing natural fractures exhibiting the major fracture coatings found at Yucca Mountain will be used. The concentration of colloids in ground waters from Yucca Mountain will be studied. The study of stability of silica colloids in ground water as a function of ionic strength and temperature will be completed.

3.2.13 Study 8.3.1.3.6.2 - Diffusion

The objectives of this study are to measure the diffusivity and kinetics of adsorption in a purely diffusive system (i.e., no advection) from the uptake of radionuclides on intact tuff as a function of time; and to conduct scaling studies to determine up to what scale the matrix diffusion model can be applied with confidence.

Activity 8.3.1.3.6.2.1 - Uptake of radionuclides on rock beakers in a saturated system. The objective of this activity is to measure the uptake of radionuclides by rock beakers as a function of time. These results will provide a baseline for the following activities on diffusion through a saturated tuff slab and diffusion in an unsaturated tuff block.

Diffusion is one of the most important mechanisms in fractured flow that can retard the migration of radionuclides through the subsurface. Experiments to investigate the diffusion of Np through rock beakers made from tuff (from the Topopah Spring Member and zeolitic Calico Hills) were completed during this reporting period. These experiments were performed using water from the UE-25 J#13 and UE-25 p#1. The data were being analyzed.

Activity 8.3.1.3.6.2.2 - Diffusion through a saturated tuff slab. The objective of this activity is to measure the diffusion of radionuclides in a purely diffusive system (no advection) by varying the thickness of the slabs of Topopah Spring Member tuff and Calico Hills zeolitic tuff.

Project scientists completed the study of the diffusion of Np (V) through intact tuffs G4-270 and G4-1532 and waters from the UE-25 J#13 or UE-25 p#1 using diffusion cell experiments. The data were being analyzed.

Activity 8.3.1.3.6.2.3 - Diffusion in an unsaturated tuff block. The objectives of this activity are to determine the distribution of radioactivity in the unsaturated tuff matrix, using an unsaturated tuff block of the Topopah Spring member of Calico Hills, and to fit the uptake of radionuclides as a function of time to a diffusion model with reactions (sorption) to determine the diffusivities and rate constants.

No progress during the reporting period; this was an out-year activity.

Forecast: Techniques will be developed and experiments conducted to study the diffusion behavior of radionuclides under unsaturated conditions utilizing blocks of intact tuff. Diffusion cell tests, water diffusion tests, rock beaker tests, and unsaturated diffusion tests will be performed. Well-characterized radionuclide solutions and tuff samples representative of hydrologic units will be used.

3.2.14 Study 8.3.1.3.7.1 - Retardation Sensitivity Analysis

The objectives of this study are to develop a conceptual geochemical-geophysical description of Yucca Mountain based on the results, data, and information generated from the geochemistry, mineralogy-petrology, hydrology, and other pertinent YMP tasks; and to determine what data may be inadequate or insufficient to make the cumulative, integrated transport calculations needed to meet the NRC and EPA regulations.

Activity 8.3.1.3.7.1.1 - Analysis of physical/chemical processes affecting transport. The objectives of this activity are to analyze all the processes that may affect transport, geochemical, physical, particulate, heat-load effects, and coupled phenomena; to support and develop those laboratory experiments designed to examine the physical and geochemical processes affecting radionuclide transport and other experimental activities under this program and the Exploratory Studies Facility tests (i.e., diffusion experiments); to correlate and validate results obtained from laboratory, Exploratory Studies Facility, and field experimental results with transport calculations.

Project scientists developed a coupled silica-deposition geochemistry model that integrates the change in precipitation and the associated porosity decrease, and associates that result with changes in porosity and permeability. This is significant because it is the first time that the effects of repository heating, geochemistry, and flow have been coupled. Initial results indicated that there is a strong coupling in the near field between these three processes and that further modeling, in which all the processes are fully coupled, should be conducted.

Activity 8.3.1.3.7.1.2 - Geochemical/geophysical model of Yucca Mountain and integrated geochemical transport calculations. The objective of this activity is to perform calculations of radionuclide transport from the repository to the accessible environment using, as a basis, an integrated, conceptual geochemical-geophysical model of Yucca Mountain.

This work seeks to provide a technical basis that will ensure that performance assessment models contain the most important geochemical phenomena and interactions for radionuclide transport. Activities include adapting a coupled reaction/transport simulator (LEHGC) to a massively parallel computing architecture. This simulator will then be used to model radionuclide transport with complex chemical behavior on the time and spatial scales required for regulatory compliance assessments.

Verification efforts for LEHGC1.0 (Yeh, 1994) were completed. The four sample problems from the LEHGC manual, a diffusion problem, a model for the YMP caisson experiment and eight HYDROGEOCHEM problems have all been successfully solved. CHEMVAL Case 1, involving the dissolution of a cement by clayey water, was also successfully run. This problem couples advective transport with chemical processes including dissolution, precipitation and complexation. Species profiles compare well to those reported by CHEMVAL participants. Iterations continued in defining the appropriate initial chemical conditions for CHEMVAL Case 2, which involves the diffusion of a high-calcium-content water through sodium bentonite. A test problem simulating transport in discrete fracture-media was also developed to test LEHGC. The model was patterned after the one described by Grisak and Pickens (1980). A preliminary configuration was run in LEHGC with promising results; however, after modifications were made to duplicate the tests described by Grisak and Pickens (1980), it was apparent that LEHGC is not duplicating their model's output.

The LEHGC Version 1.1 code and User's Manual (Hopkins et al., in prep.) was received and found to have a more efficient tracking algorithm than LEHGC1.0, and includes four preconditioned conjugate gradient methods for the solution of the matrix equations, multiple sorption and ion-exchange sites, and a base model for colloid transport.

A version of LEHGC previously modified to perform the chemical equilibrium calculations in parallel on the nCUBE was used to carry out timing studies to evaluate the benefit of executing LEHGC on a massively parallel platform. Depending on the complexity of the chemical system and the number of computational nodes in the system, an increase of up to an order of magnitude in speed could be realized by parallelization.

A draft letter report describing the status of the LEHGC2.0 was completed (Hopkins et al., in prep.). This version of the code provides a capability to simulate reactive transport in systems in which both equilibrium and kinetic descriptions of chemical reactions are needed.

Staff obtained the most recent stratigraphy data from Lawrence Berkeley Laboratory; this data incorporated the most recent USGS stratigraphy results. Project scientists have input data into the Stratamodel SGM three-dimensional visualization package and created three-dimensional images in which the elevation of surfaces defining Yucca Mountain was different from that generated by the previous approaches. Staff received a second data set from Lawrence Berkeley Laboratory and will begin analysis on that set.

GEOMESH, a finite element mesh generation software package for geological applications that has been used extensively in flow and transport modeling work, was substantially improved. This software supports the three-dimensional site-scale modeling of transport and the transport calculations described in Activity 8.3.1.3.7.1.1.

The grid effort will support the accelerated site characterization effort by allowing rapid inclusion of the latest hydrogeologic information into the transport models. The development of GEOMESH has streamlined the mesh generation process, allowing more time to be spent

on the computations and interpretation of results. The flexibility of automated mesh generation also means the modeler is not confined to a single computational grid, and the gridding process is linked to the stratigraphic data base so new grids with different resolution are simple to generate. The following advances have been made:

1. It is now possible to incorporate the potential repository horizon as part of the computational grid.

2. The ability to incorporate wells and tunnels, with arbitrary paths, has been implemented and is in the final stages of testing. This will allow accurate representation of gas and fluid flow in the vicinity of wells and tunnels.

3. The previous version of this software only allowed hexahedral elements to be divided into 24 tetrahedra, which resulted in very large grids. The code now can divide hexahedra into 5 tetrahedra without adding any nodes. This will be important for keeping the mesh size tractable in large three-dimensional calculations.

Forecast: The user's manual for LEHGC1.1 will be completed.

Activity 8.3.1.3.7.1.3 - Transport models and related support. The objectives of this activity are to verify the computer codes and to validate the models used in this study and to identify important contributors to the uncertainties in retardation calculations (sensitivity analyses).

Numerical simulation efforts focused on two types of transport calculations, Cl-36 simulations and Np transport predictions. These two-dimensional calculations used unstructured finite element grids that follow the stratigraphy of the different hydrostratigraphic units defined at Yucca Mountain to provide the most accurate results possible. The Cl-36 model results show ground water ages in the unsaturated zone that are of the same order as the measured values when infiltration rates of about 0.1 mm/yr are used. Np calculations used the latest compilation of sorption data results to set the Kd as a function of hydrostratigraphic unit. Equivalent-continuum model results showed transport times to the water table of several hundred thousand years. Dual permeability calculations, which explicitly account for the role of fractures in flow and transport, can yield transport times for Np that are even shorter (25,000 yr), but only if radionuclides are assumed to stay within the fractures with no access to the rock matrix and no sorption on fracture faces. This result is thought to be unrealistic because for reasonable diffusion coefficients, the model shows that radionuclides have ample time to diffuse into the rock matrix, where it is held up by sorption. Furthermore, sorption on calcite in the fractures is also likely to slow the movement of Np. Future modeling and experimental efforts will attempt to further refine these results to obtain more precise estimates of Np travel times. This work is significant in that it demonstrates, using diffusion data, the importance of accounting for matrix diffusion of the radionuclide when fractures are present. Without these enhancements, the travel times would be unrealistically short.

The most recent Yucca Mountain three-dimensional flow and transport results are being described by Gable et al. (in prep.)

Presentations were made at the NWTRB meeting in Denver, Colorado, on July 12, 1994. This presentation was highlighted by the dual permeability simulations described in Activity 8.3.1.3.7.1.1 and some early results on coupled geochemistry and flow. The coupled geochemical simulations revealed that the competing processes of solubility and vaporization can produce some unexpected results for the near-field. Comments made at a previous NWTRB meeting were addressed with these results.

Forecast: Processes that affect the transport of radionuclides at Yucca Mountain to support simplifying assumptions made by performance assessment for transport models will be studied. Site characterization data gathering activities by identifying important processes and specifying data accuracy requirements will be guided. A sensitivity analysis will be performed to determine effects that variations in parameters and/or processes have on transport from the repository. Key data from site characterization will be identified. A site scale model of Np will be developed. Coupled processes will be investigated and a near-field coupled-flow model will be produced; this model will be used in conjunction with testing the coupled flow geochemistry module. A cross validation of the Lawrence Berkeley Laboratory/USGS flow model will be produced using the computer code FEHM. Hydrogeologic elevation and property data made available by Lawrence Berkeley Laboratory and USGS will be used to produce a flow model. Codes to simulate various transport processes that may occur at Yucca Mountain will be developed. A particle-tracking module for FEHM will be created, which will allow evaluation of numerical errors associated with transport simulation. A flow/geochemistry module will be created, which will allow flow parameters to change with geochemistry.

A complete set of transport-related hydrogeologic framework data will be submitted to the YMP Technical Data Base, particularly delineating of mineralogic zones and any proposed correlation of such zones with transport of thermomechanical rock properties. Transmittal will be in electronic format, to the extent practical, and will represent the discrete region corresponding to the "best" simulation grids for site-scale and C-well radionuclide transport. "Base Case" distributions of retardation-related parameters will be provided and adequately supported. Computed transient concentration distributions will be provided for modeled regions, and will be accompanied by sufficient information to enable simulation results in the EarthVision environment.

3.2.15 Study 8.3.1.3.7.2 - Demonstration of Applicability of Laboratory Data to Repository Transport Calculations

The objective of this study is to outline the strategy that will be used to demonstrate the validity of the laboratory generated geochemical data and the transport calculations using that data.

Activity 8.3.1.3.7.2.1 - Intermediate-scale experiments. The objective of this activity is to conduct experiments at a scale larger than a laboratory but with sufficient control on material and boundary conditions to test how increased spatial scale affects water flow and radionuclide transport in unsaturated porous media.

No progress during this reporting period; this was an out-year activity.

Activity 8.3.1.3.7.2.2 - Field-scale experiments to study radionuclide transport at Yucca Mountain. The objective of this activity is to evaluate the validity of laboratory-derived data and models for radionuclide transport at the Yucca Mountain site by conducting tests in the bedded tuffs of the Calico Hills unit underlying the Topopah Spring unit.

Planning for an experiment in the nonwelded tuff at P-Tunnel was initiated. Project scientists will investigate advective radionuclide transport using stable-isotope tracers. This will be a model for future experiments in the Calico Hills. (P-Tunnel at Rainier Mesa on the Nevada Test Site has a nonwelded tuff unit similar to the Calico Hills geologic unit at Yucca Mountain.)

A white paper on the need for testing and early entry into the Calico Hills geologic unit was prepared. Key issues considered in the paper include (1) the need for horizontal access to intersect potential vertical fast transport paths prior to extensive perturbations, (2) whether pristine conditions are necessary so that the ambient geologic record can be used to reduce uncertainty in long-term assessment, (3) whether limiting access to the Topopah Spring Member would jeopardize the opportunity to evaluate the suitability of Yucca Mountain to minimize radionuclide migration and serve as a permanent repository, and (4) the cost effectiveness of focusing transport studies on the Calico Hills. The uses of a horizontal access in the Calico Hills include testing and long-term monitoring. These issues and others related to Calico Hills access are being analyzed in a systems study that is scheduled for completion in May 1995.

Activity 8.3.1.3.7.2.3 - Natural analog studies of radionuclide transport. The objective of this activity is to use natural analog studies and data generated by natural analog studies to support long-term calculations of radionuclide transport using laboratory data and radionuclide transport models.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.3.7.2.4 - Data on radionuclide transport from other U.S. Department of Energy sites (Anthropogenic Analogs). The objective of this activity is to evaluate the validity of laboratory-derived data and models for radionuclide transport at the Yucca Mountain site by obtaining data collected at other United States DOE sites on radionuclide distribution in geologic systems.

No progress during the reporting period; this was an unfunded activity.

Forecast: Feasibility studies of desorption/leaching will be conducted. Desorption and leaching of debris collected from a past Nevada Test Site event will be performed. Studies will determine whether drilling fluids can desorb radionuclides from tuff. Design of the proposed field tests for the Calico Hills geologic unit at Yucca Mountain will begin. These field tests will be used to evaluate new data available from the Surface-Based Testing program. A test plan for P-Tunnel work that will address archive, simulation and laboratory data needed to perform P-Tunnel tests will be developed. Simulations to predict water and tracer behavior from packed zones in boreholes will be initiated. Field tests will be performed using boreholes with packers.

3.2.16 Study 8.3.1.3.8.1 - Gaseous Radionuclide Transport Calculations and Measurements

The objectives of this study are to calculate the rates of transport of gaseous radionuclide species between the repository and the accessible environment considering the various driving forces and retardation mechanisms that may exist; and to experimentally verify potential existing models of gaseous radionuclide transport and retardation that are used to assess radionuclide release to the environment.

No progress during the reporting period; this was an unfunded study.

Forecast: As a result of the study plan work consolidation effort, no study plan is to be developed for this Site Characterization Plan section. Until NAS completes its report pursuant to Section 801 of the Energy Policy Act of 1992, and subsequent rulemaking by EPA takes place, there is ambiguity regarding the need for greater attention than already exists for gaseous transport calculations or for more field data to be collected that is already being collected under Study 8.3.1.2.2.6. If new work is needed, a new activity will be added to Study 8.3.1.3.6.1 or Study 8.3.1.3.6.2.

3.3 ROCK CHARACTERISTICS (SCP SECTION 8.3.1.4)

3.3.1 Activity 8.3.1.4.1.1 - Development of an Integrated Drilling Program

The objectives of this activity are to ensure representativeness of data acquired during surface-based site characterization activities and that data represent the range of phenomena and structural characteristics needed for performance assessment, to integrate and prioritize Surface-Based Testing activities to produce a schedule that addresses representativeness and efficacy, and to maintain a system of technical element baseline approval and control.

The YMSCO uses a consolidated work scope process as a means of integrating the site characterization drilling program. This process serves as an interface between the annual preparation of Technical Implementation Plans and use of Test Planning Packages for authorization of drilling-related Surface-Based Testing activities involving multiple investigators. The goal is to identify requirements from primary and secondary studies, and

to define a set of consolidated requirements that meet as many secondary needs as possible while not compromising the primary purpose of the activity. For example, in a borehole drilled in support of the Systematic Drilling Program, the needs of other activities can be met through distribution of core or cutting samples or through testing in the borehole after it is completed. By maximizing the benefit of each activity, the overall cost-effectiveness of the program is increased. The Catalog of Planned Boreholes (CRWMS M&O, 1993a) has resulted from this integration effort.

During the reporting period, consolidated work scopes were developed for planned Boreholes USW UZ-7a and USW SRG-3/3a

The USW UZ-7a borehole is planned to be drilled in the Ghost Dance fault zone, near existing Well USW WT-2. The USW SRG-3/3a is a pair of planned boreholes along the South Ramp alignment of the Exploratory Studies Facility. These boreholes will allow collection of stratigraphic and rock quality data for Exploratory Studies Facility design, as well as penetration of the Calico Hills formations to acquire core for radionuclide transport studies.

Forecast: There will be no study plan developed for this activity. In FY 1995, the consolidated work scope process will be combined with preparation of Test Planning Packages, and the planning information will be included in the completed packages.

3.3.2 Activity 8.3.1.4.1.2 - Integration of Geophysical Activities

The objective of this activity is to provide a mechanism for information exchange, an analysis of data and other technical information, and an overview of planned geophysical site characterization activities.

The Geophysics Integration Task Force continued to address geophysical testing issues to facilitate the efficient use of geophysical methods in site characterization. A key focus of this group during the current reporting period was the analyses of geophysical data on the orientation of the Ghost Dance fault down to repository depth to support design of the Exploratory Studies Facility.

The Geophysics Integration Task Force also completed the planning process for multiple geophysical tests within and adjacent to the potential repository area in FY 1995. A program of geophysical logging in new and existing boreholes, vertical seismic profiling, high-resolution seismic reflection lines, and associated magnetic, electrical, and gravity surveys was planned. Geophysical tests proposed for FY 1995 were examined to determine whether they supported the program priorities. Work continued on compilation and integration of existing and planned geophysical data and tests. Section 9.0 (Geophysical Studies) of the Site Characterization Activities Catalog (CRWMS M&O, 1993b) contains a compilation of geophysical tests derived from the Site Characterization Plan and individual study plans. In addition, work continued on developing a bibliography of known geophysical testing results related to the YMP and general vicinity.

During this reporting period, in addition to the scope of work of this study, a planning effort was undertaken to accumulate YMP stratigraphic information into a compendium. The compendium is intended to contain summaries of the stratigraphic units, the lithologic logs for each borehole, and to provide Project guidance on the Project-approved stratigraphic nomenclature. The Stratigraphic Compendium is intended to be a well-referenced source of stratigraphic information about the site, allow new synthesis of existing stratigraphic information, and serve as a reference guide for locating more detailed information. The compendium is intended to be a source of information for investigators, modelers,and oversight groups.

Major sections of the compendium are organized to review the Quaternary, Tertiary, and Paleozoic geologic sections that occur in the Yucca Mountain region. Other portions of the compendium will review the available geochronology, geologic mapping, and other forms of mapping at the site in the region. In addition, as more information is gained through site characterization, the compendium is intended to be updated with new borehole lithologic logs or other newly acquired geologic information. These stratigraphic data and interpretations are developed in conjunction with the integrated site model.

Forecast: There will be no study plan developed for this activity. The Geophysics Integration Task Force will continue to meet periodically to discuss, determine the need for, plan, budget, sequence, and schedule geophysical testing within the Site Characterization Program, and to ensure the application of geophysical test results within the Site Characterization Program. Consideration will be given to technological advances in geophysical methods to incorporate new and potentially useful geophysical test methods into existing and future study plans.

The Geophysics Integration Task Force will endeavor to ensure that objectives, scope, and methods for geophysical tests are well-defined, geophysical and nongeophysical testing programs are integrated, test linkages and information needs are established, the technical need and adequacy for all proposed geophysical tests is well understood, the conduct of the geophysical tests is justified, and that implementation of a geophysical test will contribute to the development of models and assessments to be used for the determination of site suitability and License Application.

A bibliography of all relevant geophysical publications will be issued in draft form for review and comment. Monthly geophysical activity summaries will be issued to the Geophysics Integration Task Force and to YMSCO. Discussions will continue between the Geophysics Integration Task Force and YMSCO on the form and content of a Geophysics Integration Plan.

A first draft of the Stratigraphic Compendium is expected in the first quarter of FY 1995 with later updates to follow on an annual or semiannual basis.

3.3.3 Study 8.3.1.4.2.1 - Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area

The objective of this study is to determine the vertical and lateral variability and emplacement history of stratigraphic units and lithostratigraphic subunits within the Yucca Mountain site area.

Activity 8.3.1.4.2.1.1 - Surface and subsurface stratigraphic studies of the host rock and surrounding units. The objective of this activity is to determine the spatial distribution, history, and characteristics of stratigraphic units within the Paintbrush Tuff, tuffaceous beds of Calico Hills, Crater Flat Tuff, and possibly older volcanic rocks within the site area.

Geotechnical staff continued developing and refining a three-dimensional computer-based stratigraphic and structural model which will be the basis for other site-scale models. A related discussion is presented in Section 3.3.5. Newly acquired qualified borehole data, revised borehole-location data, and stratigraphic data were compiled and incorporated into the previously produced LYNX software data base files.

Borehole location and stratigraphic data from 41 boreholes were compiled and reviewed. These data were used along with Scott and Bonk (1984) surface geologic data to construct one structure-contour map, ten isopach maps, and a fault-geometry map. A digitized data base, a three-dimensional lithostratigraphic model, and a secondary fault model were constructed from these maps.

Continuous reviews of the input and verification reviews of the output were performed to ensure high quality and accuracy. Five structure-contour maps, four isopach maps, and four cross sections were prepared from the combined computer data base and verification reviews were completed by converting surface descriptions and cross sections into working-draft hard copies using AutoCAD.

Geotechnical scientists prepared a computer tape using LYNX software for YMP participant use on the distribution of lithostratigraphic units within the central block of Yucca Mountain. The three-dimensional model consists of seven modeled blocks, which are typically fault bounded, and 11 surfaces representing lithostratigraphic units in each modeled block.

Project scientists created preliminary cross sections from the three-dimensional lithostratigraphic solid model for Boreholes USW NRG-7/7a and USW NRG-6. These cross sections will assist in locating instruments for unsaturated-zone studies which will examine changes in the pneumatic environment after the passing of the tunnel boring machine in the Exploratory Studies Facility.

Technical staff developed computer programs which convert the fracture data base to graphical ARC/INFO or AutoCAD software drawings. The data base plot, including dip amounts and strike direction, was used to review and revise the original fracture data base of the Ghost Dance fault area and create final draft maps for Activity 8.3.1.4.2.2.1, Geologic

mapping of zonal features in the Paintbrush Tuff. The results will be used in addressing the issue of ground-water travel time.

Analyses of core samples of the Tiva Canyon Tuff from Drillhole UE-25 NRG#3 indicate that concentrations of certain trace elements vary systematically with stratigraphic position, and sharp changes in concentration mark the boundary between the high-silica rhyolite (upper lithophysal zone) and quartz latite (upper cliff zone) compositional zones in the Tiva Canyon Tuff. Strontium isotope compositions at the time of eruption of the tuff are fairly constant in the high-silica rhyolite, but decrease in the quartz latite. These geochemical data will help to determine stratigraphic position and test for fault offsets during underground mining operations. An open-file report summarizing x-ray fluorescence geochemical data along with Rb-Sr isotopic data on the high-silica rhyolite and quartz-latite cap rock was completed (Peterman and Futa, in prep.).

To examine further stratigraphic relationships, geologists examined core from USW G-4 between 69 and 161 m depth near the top of the Topopah Spring Tuff. Twenty-one samples of moderately to densely welded tuff matrix and pumice clasts were sampled for geochemical analyses.

Field geologists working on a faulted area at the eastern end of Antler Ridge are using x-ray fluorescence analysis to distinguish between the upper lithophysal zone (high-silica rhyolite) and the upper cliff zone (quartz latite) in order to verify the field picks of the contact between the two zones.

Yucca Mountain scientists compiled a geochemical data base of major and trace element data obtained from whole-rock analyses of samples recovered from Boreholes USW G-1 and USW G-3/GU-3. Graphs were made to illustrate major and trace element concentrations with respect to stratigraphic position. The data are described by Singer et al. (in prep.) and the results will make it possible for accurate stratigraphic positions to be determined in the Exploratory Studies Facility where enhancement of features by surficial processes will be lacking.

Yucca Mountain scientists continued lithologic logging of new and existing boreholes. Preliminary descriptions of lithologic contact tables were completed for Boreholes UZN-N11, USW UZ-14 and USW NRG-7/7a. Tables of lithologic contacts were completed for Boreholes USW NRG-7/7a, USW UZ-N11, -N15, -N16, -N17, -N36, -N38, -N64, USW UZN#63, and USW SD-9. Detailed graphical lithologic logs were completed for Boreholes UE-25 NRG#2c and NRG#2d, USW SD-9, and USW NRG-7/7a. Data were entered into the LYNX three-dimensional lithostratigraphic site-scale solid model.

The FY 1994 lithologic logging of new and existing boreholes work is reported by Geslin et al. (in prep.) and Geslin and Moyer (in prep.).

Project scientists examined the Calico Hills Formation and Prow Pass Tuff in the C-well complex in outcrops at Prow Pass and Raven Canyon, and the Calico Hills Formation in an outcrop at Busted Butte. They continued to synthesize lithostratigraphic data, to prepare

unit descriptions, to define criteria to identify contacts, and to compare lithostratigraphic divisions to geochemical, mineralogical, and geophysical data collected from the literature. Thin sections were prepared from 54 samples for petrographic analysis. Detailed knowledge of these units will be used to evaluate their possible role in retarding the migration of any released radionuclides.

Project scientists completed final checks of the lithostratigraphic data for the Prow Pass Tuff and the Calico Hills Formation in Boreholes USW G-1, G-2, GU-3, and G-4, UE-25 a#1, UE-25 c#1, and c#2 and field observations from Raven Canyon and Prow Pass; and lithostratigraphic data for the Prow Pass Tuff and the Calico Hills Formation in Borehole UE-25 UZ#16. A proposed publication describing the lithostratigraphy of the Calico Hills and Prow Pass tuffs (Crater Flat Group), by Moyer and Geslin (in prep.), include tables-to-depths of lithologic contacts in the boreholes examined, unit descriptions, contact descriptions, contoured unit thickness maps, and measurements of pumice elongation in the Prow Pass Tuff.

Based on the acquisition and synthesis of lithologic data under this activity, the project now has lithostratigraphic data from all intermediate to deep boreholes located and checked for consistency within one data base. With the use of the data base in a LYNX Geosystems format the project now has the ability to view the geometric positions of eleven layers from the base of the Topopah Spring Tuff upward to the surface. These geometric relations of structural and lithologic components can be used to update hydrologic modeling of the unsaturated zone and aid in the design of the Exploratory Studies Facility and potential repository within the central block of Yucca Mountain.

Activity 8.3.1.4.2.1.2 - Surface-based geophysical surveys. The objective of this activity is to improve confidence in stratigraphic models of Yucca Mountain by incorporating geophysical constraints.

Gravity and ground magnetic measurements obtained across the Ghost Dance fault at the end of FY 1993 were processed for initial modeling efforts. Staff completed terrain corrections for gravity readings from 28 stations and prepared preliminary magnetic model figures representing a general concept of magnetic profiles. Gravity and magnetic measurements were obtained along approximately five line-miles located along three main lines and several short secondary lines crossing the Ghost Dance fault. The data are consistent with multiple breaks noted during surface mapping and will be useful for design purposes for the Exploratory Studies Facility as well as input to estimates of ground-water travel time.

Gravity and magnetic anomalies data obtained near the North Ramp alignment were prepared for modeling. Geologic details were integrated with geophysical data to clarify and refine the model interpretations. Physical property data and well-log information for the rock units involved in the modeling were collated. Preliminary geologic/geophysical cross-sections were developed for several lines and preliminary gravity and magnetic models were generated for five points. Preliminary gravity and magnetic models were generated for areas in Midway Valley and Yucca Wash. Interpretations of Yucca Wash were much more complicated

because of the transition between Yucca Mountain and the Timber Mountain caldera to the north. In addition, in the Yucca Wash area, geologic information is not as detailed as in Midway Valley. Detailed studies of this area are important because of the steep hydraulic gradient beneath the area studied.

Sikora et al. (in prep.) report results of aeromagnetic surveys conducted during FY 1993 in Crater Flat along the approximate trace of the planned seismic reflection profile. The report has plates with profiles at scales of 1:48,000 and 1:100,000 to facilitate overlay on geologic maps and represents production at a more useful scale.

Scientists reviewed identification of a faulted structure near the northern Ghost Dance trace in Coyote Wash by electrical methods. A review of vertical seismic profiling, surface seismic reflection, gravity, and magnetic studies of the Ghost Dance fault system was completed. Conclusions reached regarding data in the region near Boreholes USW WT-2 and UE-25 UZ#16 were that magnetic results to shallow depths and vertical seismic profiling/seismic methods to greater than 610 m depth appear consistent with geology mapped from surface exposures.

The acquisition of gravity and ground magnetic data in Midway Valley, Yucca Wash, and across the Ghost Dance fault has provided an inexpensive means of identifying the existence of buried faults. Several new faults have been identified east of the Bow Ridge fault and in the middle of Midway Valley. No faults with significant vertical separation were identified in Yucca Wash. A detailed magnetic profile across the Ghost Dance fault suggests that this fault has a unique signature, which may be related to alteration at depth. Seismic-reflection profiles across the Ghost Dance fault confirm surface mapping results, which suggest the fault is a zone 60-100 m wide and extending to depths greater than 762 m.

Activity 8.3.1.4.2.1.3 - Borehole geophysical surveys. The objectives of this activity are to aid in the definition and refinement of the location and character of lithostratigraphic units and contacts between units and to determine the distribution of rock properties within lithostratigraphic units.

Geophysical scientists prepared a data report on the magnetic properties of Boreholes UE-25 UZ#16, USW WT-2, and USW NRG-6 (Nelson, in prep.). The report detailed the tool performance and displayed plots of the well logs.

Activity 8.3.1.4.2.1.4 - Petrophysical properties testing. The objective of this activity is to provide geophysical and rock property data to be used in the interpretation of surface-based and borehole geophysical surveys.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.4.2.1.5 - Magnetic properties and stratigraphic correlations. The objective of this activity is to provide magnetic property data to aid in the interpretation of volcanic stratigraphy and structure of rock units, to use paleomagnetic directions to provide

orientations for drill core segments, and to assess the rotation of rock units in relation to the geologic structures of Yucca Mountain from paleomagnetic indications.

No progress during the reporting period; this was an unfunded activity.

Forecast: Modeling of lithostratigraphic surfaces will continue in FY 1995 to include significant surfaces in the Calico Hills Formation and Crater Flat Group to assist hydrologic modeling of the unsaturated and saturated zones. Area of coverage may be expanded to the east and southeast to assist in modeling of potential flow pathways.

Gravity and ground magnetic profiles will be acquired along east-west valleys and ridges within the central block and in the Jet Ridge area to aid in the identification of potentially buried or concealed structures. Acquisition of seismic reflection data will be conducted along a regional line crossing Crater Flat and Yucca Mountain. Processing of seismic data and interpretation of results will begin. Magnetic data will be acquired along the seismic line.

Draft manuscripts reporting aeromagnetic investigations along the planned trace of the seismic reflection profile and compilation of geophysical results are in review.

3.3.4 Study 8.3.1.4.2.2 - Characterization of the Structural Features Within the Site Area

The objective of this study is to determine the frequency, distribution, characteristics, and relative chronology of structural features within the Yucca Mountain site area.

Activity 8.3.1.4.2.2.1 - Geologic mapping of zonal features in the Paintbrush Tuff. The objectives of this activity are to map zonal variations within exposed tuffs that will aid in the identification of structural displacement at a scale of 10 m or less; and to detect subtle changes in structural styles.

Final compilation and redrafting of geologic maps of a portion of the Ghost Dance fault and Sundance fault area were completed. Extensive technical peer reviews were conducted both in the field area and of the draft maps. New field work, map revisions, and modifications were completed based on comment resolution of the peer review. Braun et al. (in prep.[a]) describe this work in a paper covering detailed geologic maps along the Ghost Dance fault at Yucca Mountain.

Geologists mapped the lithologies and structures at a scale of one inch equals five feet at the Antler Ridge (ARP-1) exposure. These data were combined with fracture mapping results from Activity 8.3.1.4.2.2.2 (Surface-Fracture Network Studies). The ARP-1 exposure report by Braun et al., (in prep.[b]) describes this work. These data will support modeling of the unsaturated zone hydrology and the issue of ground-water travel time.

Yucca Mountain geologists prepared measured sections of the Calico Hills Formation in upper Paintbrush Canyon. Rock specimens collected from Solitario Canyon and core samples from Borehole UE-25 NRG#4 were prepared for thin section and geochemical analysis to support Exploratory Studies Facility design. Information from the rock suite was used as part of the geochemical reference section and in support of the mapping activities within the site area to better define lithologic zones and zonal boundaries.

Samples of Tiva Canyon Tuff acquired in a faulted area at the eastern end of Antler Ridge were prepared for x-ray fluorescence analyses. Geologists examined subhorizontal vapor-phase partings in the upper Tiva Canyon Tuff in the Exploratory Studies Facility Alcove #1 and drainage cuts above the portal to interpret the stratigraphy. They examined rocks in outcrops along Abandoned Wash and in core from Boreholes USW UZ N-32 and UE-25 UZ#16. Samples were taken from pyritized areas of core from USW G-2 for thin section and geochemical analyses in support of Study Plan 8.3.1.9.2.1. (Natural Resource Assessment of Yucca Mountain, Nye County, Nevada).

Staff summarized data from the opaque mineral phases that characterize each zone within the Tiva Canyon Tuff in Antler Ridge and in Borehole USW GU-3. Tables showing the opaque mineral phases identified with respect to stratigraphic position were created. Minerals were examined to determine change with respect to stratigraphic position within the Tiva Canyon Tuff. Singer et al. (in prep.) describes this work, which is based on borehole samples from USW G-1 and USW G3/GU-3.

X-ray fluorescence analyses of a series of seventeen rock samples of Tiva Canyon Tuff from the excavated North Ramp drainage channel at Exile Hill were used to determine whether the contact between the upper cliff member (quartz latite) and upper lithophysal member (high-silica rhyolite) is present in this channel. It was determined that all samples reflect the chemical characteristics of the quartz latite cap rock, and that the contact with the underlying high-silica rhyolite lies stratigraphically below the sampled horizons.

In the Raven Canyon and Paintbrush Canyon reference sections, two areas of high topographic relief, the same volcanic rocks that are encountered in drillholes and excavations at Yucca Mountain are exposed at the surface. At these localities, the volcanic rocks are minimally altered, and the sections can serve as reference sections for purposes of determining alteration of the units within Yucca Mountain. Also, the alteration exhibited by the older units (pre-Paintbrush Group) may serve as an analog for alteration that could occur in the Topopah Spring Tuff in the near field of the potential repository due to thermal loading. An open-file report was in review (Peterman et al., in prep.)

Revised detailed geologic maps of the Ghost Dance and Sundance fault systems have now been reviewed and field checked to expedite publication and distribution. Changes resulting from that review include adding degrees of confidence for all contacts and structures to reflect the amount of cover and/or to what extent the contacts were approximately located.

Detailed mapping conducted of the 183-m long exposure across the Ghost Dance fault has confirmed the existence of structures discovered during earlier mapping. The maps show

the distribution of fracture intensity and clearly expose both northwest-trending faults and brecciated rock as well as several north-trending structures. These features will have to be considered in Exploratory Studies Facility design and in meeting the qualifying conditions noted in 10 CFR 960.4-2-3(b).

Use of trace-element distribution in boreholes and outcrop was used to identify and confirm the contact between the quartz latite and the rhyolite in the Tiva Canyon tuff and Topopah Spring tuffs. This method will be used to determine amounts of vertical separation across faults and fault zones and can be used to determine stratigraphic position during construction of the Exploratory Studies Facility.

Activity 8.3.1.4.2.2.2 - Surface-fracture network studies. The objective of this activity is to provide measurements and analyses of fracture networks to support modeling of hydrologic potential flowpaths, particularly in unsaturated zones. Applications are also expected to aid development of tectonic models and determination of the mechanical response of fractured rock to excavation and thermal loading.

Project mappers completed fracture mapping of the Antler Ridge (ARP-1) exposure. These data were forwarded to geologic mappers working on Activity 8.3.1.4.2.2.1, Geologic mapping of zonal features in the Paintbrush Tuff, for incorporation into a final ARP-1 map report. Mapping of fractures exposures of ARP-1 indicate a preferred northwesterly fabric within the Ghost Dance fault system as had been previously mapped in partially covered areas at a scale of 1:240.

Activity 8.3.1.4.2.2.3 - Borehole evaluation of faults and fractures. The objectives of this activity are to assess the reliability and usefulness of available borehole techniques for identifying and characterizing the subsurface fracture distribution; to determine vertical and lateral variability and characteristics of subsurface fractures; and to identify subsurface characteristics of fault zones.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.4.2.2.4 - Geologic mapping of the Exploratory Studies Facility. The objectives of this activity are to determine the vertical and horizontal variability of fracture networks in the Exploratory Studies Facility ramps, drifts, and boreholes; to characterize major faults and fault zones in the subsurface; to map the lithostratigraphic features of the subunits and the abundance and character of lithophysal zones; and to assist in the evaluation of test locations in the Exploratory Studies Facility test facility.

The geology of the Exploratory Studies Facility North Portal investigations included geologic mapping of the Starter Tunnel, Test Alcove #1, and the drainage channel. Photogrammetric full-periphery-mapping fracture analysis, and geotechnical analysis of the Starter Tunnel and alcove work was performed. Samples from the North Ramp Box Cut and Drainage Channel were collected and submitted for trace element analysis. Consolidated sampling in Test Alcove #1 was completed

Project scientists completed preparations to begin geologic mapping behind the tunnel boring machine. Equipment was assembled and the staff completed a job safety analysis for geologic mapping and orientation, and a geologic overview and underground training course. The Technical Procedure was also completed.

Mapping of the Starter Tunnel, Test Alcove #1, and the drainage channel provided the basic geologic framework of the east end of the North Ramp. Geologists provided geotechnical data and analysis to the tunnel designers to assess the adequacy of ground support and other safety factors in the Starter Tunnel and alcove

Mapping of contacts and fractures within the Starter Tunnel, Test Alcove #1, portal cut, and drainage channel have been completed. Compilation will allow inspection of trends of fracture systems for areas exposed during construction progress in FY 1994.

A report describing the geology of the Exploratory Studies Facility North Ramp Portal area and Starter Tunnel is in preparation.

Activity 8.3.1.4.2.2.5 - Seismic tomography/vertical seismic profiling. The objectives of this activity are to investigate, and if successful, provide a means for broadly detecting and characterizing the subsurface fracture network in regions between the surface, boreholes, and underground workings; and to calibrate and relate the seismic propagation characteristics of the host rock to the fracture patterns observed in boreholes and underground workings, and extrapolate the observed fracture patterns to the surrounding region.

Researchers further refined the vertical seismic profile and surface reflection data. Interpretation of the data may provide for broadly detecting and characterizing the subsurface fracture network in regions between the surface, boreholes, and underground workings. A second generation of interpretation was carried out on the surface reflection data and compared to the existing three-dimensional site scale model. Data were compared and faults with a high degree of confidence were transferred to the site scale modelers for integration into the LYNX data base in support of Activity 8.3.1.4.2.1.1, Surface and subsurface stratigraphic studies. The far-offset data from Boreholes USW WT-2 and USW NRG-6 were further processed for refining the images associated with faulting in the vicinity of these wells. Data indicated that in the case of Borehole USW WT-2 there is clear evidence from the far offset vertical seismic profile at 305 m that the Ghost Dance fault is a system of faults in a zone at least several hundred feet wide and extending at least 305 m deep. Final processing was carried out on the USW WT-2 and USW NRG-6 vertical seismic profile data in conjunction with the interpretation of the surface reflection results.

Work was completed on the development and validation of interpretational codes ANI90 and CART. Test simulations were run for testing sensitivity of the codes and for testing the effect of subtle and sharp velocity variations in lithology.

Scientists acquired and analyzed additional field data from surface-reflection surveys. An improved depth section using a refined velocity model was obtained and the images along Lines 1 and 2 were improved. Further processing and display of the data showed deeper

reflections beneath the Calico Hills Formation that had previously been observed. Deeper reflectors along Line 1 indicate that the Ghost Dance fault penetrates the entire section, over 1219 m, and maintains the same dip. This work imaging the subsurface structure and lithology at Yucca Mountain were reported in a paper by Daley et al. (in prep.).

Forecast: The combined detailed structural mapping coupled with surface geophysics will continue within the central block to better understand the northwest-trending structural fabric. Underground mapping will keep pace with construction.

3.3.5 Study 8.3.1.4.2.3 - Three-Dimensional Geologic Model

The objective of this study is to develop a three-dimensional geologic model of the site area. In doing so, much of the study will involve synthesis of the results of other studies in the investigation to develop a model that will be integrated into the three-dimensional rock characteristics model described in Study 8.3.1.4.3.2 of Investigation 8.3.1.4.3.

An extended three-dimensional site geologic model, which was not part of the work scope of this study, has been started. This extended site model is to gather all available stratigraphic and structural information at Yucca Mountain and create a geologic framework three-dimensional model which will include more data and wider boundaries than has been accumulated previously.

During FY 1994, effort was spent primarily on gathering stratigraphic data from 97 boreholes. During the fourth quarter, data were entered into the three-dimensional model for initial editing and evaluation. Other work consisted of:

- Additional stratigraphic data were obtained for Drillholes USW SD-9 and SD-12. The locations of these holes makes them highly valuable to three-dimensional modeling because they provide data within the proposed repository block.

- Additional sources of stratigraphic data were also obtained for seven NRG holes and two RF holes. For the seven NRG holes, data from USGS/Science Applications International Corp. and SNL have been compiled.

- In conjunction with the Stratigraphic Compendium (Section 3.3.2), the tabulated stratigraphic data were thoroughly reviewed and analyzed. Several clarifications, additions, and deletions were found to be necessary. In addition, stratigraphic data were scrutinized for compliance with current USGS stratigraphic nomenclature.

- Borehole stratigraphic data were given to EG&G for preliminary analysis via three-dimensional modeling using the EarthVision software system.

- As a first step in modeling, faults at Yucca Mountain were studied and selected for inclusion in the three-dimensional model. The faults chosen are: Paintbrush Canyon, Bow Ridge, Solitario Canyon, Ghost Dance, Windy Wash, Yucca Wash,

Pagany Wash, Sever Wash, Fran Ridge, Drillhole Wash, Dune Wash, Boomerang, Jet Ridge, and Abandoned Wash. These were chosen on the basis of offset, strike length, intersection by boreholes, geographical distribution, and location with respect to the Exploratory Studies Facility; thus, the known faults which may affect future Project decisions are included. Fault traces were extracted from Scott and Bonk (1984), as were dip and offset information. Fault dips were then adjusted to match borehole intersections. Dealing with faults in three-dimensional models is difficult by virtue of the necessary interpretation of fault offset, geometry, and deformation required in a representation. Future revisions to the fault geometries are expected as further information is gained from drilling and surface activities.

- Compilation of rock properties data was initiated for addition to the three-dimensional geologic model. Several new spreadsheets were created which contain data including bulk density, porosity, sonic velocity, and water content. These data will be included in the integrated three-dimensional site model. Additional data will be obtained in FY 1995.

Forecast: In early FY 1995 the integrated three-dimensional site model effort will model the faults and evaluate their individual characteristics and geometrical relationships. Modeling of depositional surfaces, volumes for each lithologic unit, and rock properties data will be compiled during the first and second quarters, and entered into the model during the second and third quarters. Ongoing evaluation and modification of the model components will continue throughout FY 1995, with a "final" interim model to be produced before the end of the year.

3.3.6 Study 8.3.1.4.3.1 - Systematic Acquisition of Site-Specific Subsurface Information

Only one activity is planned under this study. The objective of this study is to acquire physical rock samples, analytical data, and basic descriptions of the subsurface geology of the repository site on a systematic basis. These samples and information are important for characterizing the three-dimensional distribution of rock characteristics, and hydrologic and geochemical variables, for the unsaturated zone at Yucca Mountain.

Activity 8.3.1.4.3.1.1 - Systematic Drilling Program. The purpose of the Systematic Drilling Program is to acquire physical rock samples, analytical data, and basic descriptions of the subsurface geology of the potential repository block for characterizing and evaluating the three-dimensional distribution of rock characteristics, hydrologic and geochemical parameters. Core samples taken from selected drillholes provide information related to the design of the Exploratory Studies Facility Main Test Level and relevant geologic information required for understanding the deeper portions of the repository block.

Original plans for FY 1994 included drilling two SD-series holes, USW SD-9 and USW SD-12, located approximately one-third and two-thirds (respectively) of the way from north to south along the main Exploratory Studies Facility drift. Preparations for a third drillhole, USW SD-7, were completed during the reporting period. Drillhole USW SD-7 is a

combined Exploratory Studies Facility South Ramp/Systematic Drilling Program drillhole, and is located approximately where the Exploratory Studies Facility Main Test Level drift and South Ramp meet.

Drillhole USW SD-12 was cored to a depth of 1401 feet (427.31 m), well below the intended depth of the Exploratory Studies Facility Main Test Level, and of sufficient depth to provide data for immediate design requirements. Drilling was suspended during August 1994 because of continuing problems with the mechanical integrity of the dual-wall drill pipe, but will resume when new drill pipe is procured and delivered. Geologic logging of the core has been completed to 1399 feet (426.70 m).

Drilling of hole USW SD-9 commenced May 17, 1994. Perched water was encountered at approximately 1353 feet (412.67 m) depth during July; drilling was temporarily suspended at a depth of 1489 feet (454.15 m) because of continuing inflow of water. Downhole video examination of the hole to a depth of 1440 feet (439.2 m) suggested that the zone of influx was restricted to a flowing fracture near 1350 feet (411.75 m). Drilling resumed and water was encountered again at approximately 1800 feet (549 m).

On May 3-4, 1994, a presentation was made to an NRC field-review panel at Area 25 of the Nevada Test Site. The presentation reviewed the status of the Systematic Drilling Program. Specific topics included the then-current status of Drillhole USW SD-12, changes to the locations and pattern of SD holes resulting from redesign of the Exploratory Studies Facility ramps and Main Test Level drift, and integration of the Systematic Drilling Program with Exploratory Studies Facility design activities and associated laboratory testing programs.

A review was conducted of spatial correlation information from the various surface transects that have been collected since 1990 and a summary evaluation was developed (McKenna and Rautman, in prep.). The report reevaluates the conclusions of a number of publications with the objective of confirming or recommending changes to current downhole sampling patterns for the drilling program. Recommendations in the report include those with respect to how to reduce the sample spacing with least impact on the overall description of spatial variability of properties, if constraints indicate the current pattern cannot be maintained throughout the Site Characterization Program. The underlying data from the surface transect studies are contained in two reports by Rautman et al. (in prep.) and by Flint et al. (in prep.).

Forecast: Field and laboratory activities associated with Drillholes USW SD-12 and SD-9 will continue from FY 1994 into FY 1995. Geologic logs will be completed for these holes, including description of lithology, welding and alteration, and fracturing. Laboratory measurement of framework material properties and hydrologic-state variables will be completed and compiled in association with the geologic logs. Because of the extensive drilling-related delays, data will be made available to the Exploratory Studies Facility designers and other users, including performance assessment analysts, through an FY 1994 year-end Technical Data Information Form submittal to the Technical Data Base, and other submittals tied to achievement of specific drilling depths. Based on the current FY 1995 drilling schedule, field and laboratory activities will be conducted in support of planned hole USW SD-7. Remaining prerequisites for drilling will be completed as appropriate. Once

drilling of these holes begins, geologic logging and laboratory measurement of framework rock properties and hydrologic-state variables will be conducted. Results will be provided to designers and other parties through a series of episodic Technical Data Information Form data submittals tied to specific drilling depths.

3.3.7 Study 8.3.1.4.3.2 - Three-Dimensional Rock Characteristics Models

The objective of this study is to produce spatially variable numerical models of material properties for use in various Exploratory Studies Facility design evaluation and performance-assessment analyses, principally using geostatistical and other computer modeling methods. The study also will support development of new computer algorithms and computer software required to accomplish the modeling.

The study plan was sent to YMSCO on April 25, 1994. Review comments were received in late August 1994, and a revised version of the study plan is being prepared as part of comment resolution.

Activity 8.3.1.4.3.2.1 - Development of three-dimensional models of rock characteristics at the repository site. The objective of this activity is to develop computer-based three-dimensional models that integrate quantitative and semiquantitative data on rock characteristics in light of constraining information developed by studies of the geologic framework of the Yucca Mountain site.

As a follow-on to the Total System Performance Assessment - 1993 (Wilson, et al., 1994; Andrews et al., 1994), the performance consequences of the stratigraphic uncertainty indicated by the stochastic lithologic model (Rautman and Robey, 1994) were evaluated. Variations of three to eight orders of magnitude in calculated radionuclide release rates were identified, depending upon which of the eight areally-distributed one-dimensional columns was considered. Total releases from the entire repository region were dominated by those from one particular column in the northern portion of the repository block where the flow path to the water table is shortest (Wilson and Robey, 1994). The interpretation that total radionuclide releases may be driven by releases from a small portion of the overall repository block may have significance for identifying specific regions for additional site characterization and for repository design.

A summary of the geometric and geostatistical modeling of rock-quality data values from the Exploratory Studies Facility North Ramp drillholes using the LYNX geotechnical modeling system was developed (Zelinski, in prep.), and is currently in review. The two-dimensional model results are relevant to ongoing Exploratory Studies Facility North Ramp design activities, and they represent the first attempts to make location-specific predictions of ground conditions along the projected trace of the North Ramp. Previous estimates of anticipated ground conditions have emphasized simply the expected proportion of various categories of ground support that will be required.

A plan describing the theory and mechanics of using stratigraphic information as soft data to constrain geostatistical simulation of material properties has been developed and documented (Cromer and Rautman, 1994a). An updated progress report was also issued (Cromer and Rautman, 1994b). The concept makes use of stratigraphic unit assignments obtained from the three-dimensional geologic model of the site, currently being developed using the LYNX GMS modeling package. At any unsampled point, a prior estimate, or expected value, for the material property is deduced based on the geologic unit inferred at that location. This information is "soft," in that it is subject to modification if other, "hard" (i.e., measured) data are available nearby. In regions far removed from hard drillhole data, however, the modeled value will tend to reflect the geologic interpretation. This partial dependency upon an externally developed geologic interpretation is in contrast to a purely stochastic modeling approach, which has been demonstrated (Rautman and Robey, 1994) to produce material-property artifacts that are inconsistent with the conceptual geologic model of Yucca Mountain.

A new geostatistical modeling exercise was initiated in support of repository design activities evaluating thermal effects resulting from the emplacement of hot waste in a potential repository. The intent of the exercise was to identify the effects of spatial heterogeneity on the conduction of heat away from the repository region. The initial evaluation focused on comparisons of peak temperatures and temperature profiles resulting from typical simplified models invoking uniform homogeneous thermal properties or layered homogeneous properties (in contrast to a geostatistically-based model of heterogeneous, but spatially correlated, properties). The geostatistical model comprises a two-dimensional cross section of Yucca Mountain. Measured porosity values from a composite drillhole were mapped onto the cross section, and a quantitative spatial-continuity model was used to expand the measured values away from their physical location. The final geologically-based model of thermal conductivity was then used as input to a finite-element heat-conduction computer code, which computed the temperature field resulting from a specified heat source. Results indicate that predicted peak temperatures are higher close to the repository for both the model with homogeneous layers and the model with geostatistically based heterogeneity, when compared to the uniform homogeneous-property model. These higher temperatures result from the modeled presence of low-conductivity (i.e., insulating) nonwelded units both above and below the repository heat source. The geostatistically based heterogeneous-property model allowed the use of a simple, regularly spaced, computationally efficient finite-element mesh for the thermal calculations, whereas the layered homogeneous model involved a highly complex (and thus computationally inefficient) customized mesh to capture both the geometry and material-property distribution of the various geologic units (Longenbaugh et al., in prep.).

Several new developments in geostatistical modeling were reported at the annual review meeting of the Stanford Center for Reservoir Forecasting. The developments reported are: (1) methods for scaling-up small-scale measurements of permeability to represent flow-model-sized grid blocks, (2) improved methods and algorithms for reproducing targeted global statistical properties of simulated models, (3) several new algorithms and computer codes for producing geostatistical models, and (4) description of a geostatistical method for modeling fracture networks.

Item (1) is of particular interest to the Project as essentially all rock-property measurements are performed on small core samples, yet the values obtained by these measurements must be applied to grid blocks up to several hundreds of meters across. The "effective" flow property of a block of this size may be very different than any one measured value contained within that volume or than any straightforward average of measurements.

Item (2) relates principally to increasing the speed at which geostatistical models can be generated or to reducing the number and severity of numerical artifacts that may be produced during a modeling exercise. The result is models that are more "realistic" in terms of their statistical resemblance to what is known about the Yucca Mountain site through measured data. Item (3) is similarly related to reducing numerical artifacts, and to increasing the statistical similarity of models and "reality."

Item (4) may represent significant progress in quantitative modeling of "effective" rock properties because fractures may be particularly important in influencing ground water flow. Representation of fractures has previously been limited to discrete-fracture methods or unconditional, parametric simulations of various types. The new method can condition fracture models to site-specific observed information while maintaining the computational efficiency of nondiscrete modeling methods. A report summarizing the meeting discussions was forwarded to YMSCO on July 19, 1994 (Rautman and Cromer, 1994).

Work was initiated as part of a performance assessment integration activity to investigate the use of geostatistical simulation in upscaling small-scale (core) measurements of hydrologic properties to represent flow-and-transport model grid-block scales. The variability of small-scale properties is known to be larger than that of those same properties measured at a larger scale. However, for flow properties such as hydraulic conductivity, the scaling relationship is neither linear nor straightforward. Use of small-scale values to represent large grid blocks may significantly distort the results of numerical flow modeling.

Another performance assessment integration activity involved determining the feasibility of deriving three-dimensional models of radionuclide sorption potential by constructing models from mineralogy data. Mineralogy data are more easily obtainable than direct measurements of sorption coefficients. Examination of the mineralogic and sorption data indicated that both types of data are too sparse spatially at this time to construct meaningful models. This work is summarized in an informal progress report (Ward and Siegel, in prep.).

Forecast: The revised draft study plan, incorporating comments received in August 1994 by mid October 1994, will be submitted to YMSCO for final approval.

Geometric and geostatistical modeling of the Yucca Mountain site will continue with particular emphasis on specific Exploratory Studies Facility design and performance assessment problems. Development of models of thermal properties, probably using widely distributed measurements of porosity as a surrogate for thermal conductivity, will progress from two-dimensional representations to fully three-dimensional models. These material-property models will be evaluated as part of ongoing design efforts to identify

suitable thermal loadings of a repository and the likely effects of such loads on temperature profiles. Modeling to support ground-water travel time calculations will begin as part of Technical Site Suitability. Modeling of both unsaturated and saturated zone flow paths will be conducted. Major emphasis will be placed on quantifying the geologic uncertainty associated with estimates of ground-water travel time.

Investigation of computationally feasible numerical techniques for upscaling small-scale (core) measurements of hydrologic properties to represent effective property values at the geostatistical grid-block scale and at the flow/transport model grid-block scale will continue. Ground-water travel time calculations depend on using upscaling algorithms.

Efforts will continue into FY 1995 to integrate soft information from geologic models into Gaussian-based geostatistical simulation algorithms. The linked LYNX-GSLIB modeling software will be demonstrated through construction and evaluation of prototype models. Successful implementation of this software will be used in support of ground-water travel time studies.

3.4 CLIMATE (SCP SECTION 8.3.1.5)

3.4.1 Study 8.3.1.5.1.1 - Characterization of Modern Regional Climate

The objective of this study is to provide a baseline and a background for the interpretation of climatic variation. These data will be used in the development of modern vegetation-climate calibration requirements, in the assessment of lake-climate relationships, and in the development and testing of climate circulation models and in specifying relationships between global-scale circulation patterns and the regional and local climate features of relevance to site performance.

Activity 8.3.1.5.1.1.1 - Synoptic characterization of regional climate. The objectives of this activity are to provide the basis for developing vegetation-climate relationships, lake-climate relationships, and climate-circulation models (meteorological data); to provide an understanding of spatial and temporal variation in climate (synoptic climate); and to determine the climate conditions (i.e., time, temperature, seasonality, and air masses) under which recharge occurs (isotopic data).

Comments on the revised study plan were resolved, and it was approved by DOE in July 1994 and submitted to NRC in August 1994. No other progress occurred during the reporting period; this was an unfunded activity. Precipitation samples were collected during this time as part of Activity 8.3.1.5.2.1.5, studies of calcite and opaline silica vein deposits. In anticipation of reactivation in FY 1995, a regional network of precipitation collection sites has been identified; these include stations operated by both YMP participants and outside sources. These sites are considered critical to support of various site characterization activities and are needed to provide a clear regional analysis of precipitation stable-isotopic composition and its impact on reconstruction of past ground water recharge and discharge, and past climates.

Forecast: Where needed, precipitation collectors will be installed at the identified precipitation collection sites and monitored according to the Technical Procedure, which is in review. Determination of the deuterium and ^{18}O isotopic compositions of the accumulated backlog of precipitation samples will be initiated, and a data report including maps of monitoring sites and correlation plots for precipitation δD and $\delta^{18}O$ values will be prepared. Due to funding constraints, determination of Sr isotopic compositions will not be attempted in FY 1995.

3.4.2 Study 8.3.1.5.1.2 - Paleoclimate Study: Lake, Playa, and Marsh Deposits

The objective of this study is to establish the nature, timing, duration, and amplitude of paleoclimate changes in the Yucca Mountain area, based on paleontologic, geochemical, stratigraphic, sedimentologic, and geochronological data obtained from lacustrine, playa, and marsh sediments in or near southern Nevada.

The Lake, Playa, and Marsh Deposits studies and the Terrestrial Paleoecology studies (Activity 8.3.1.5.1.3) are closely interrelated. The paleontological and pollen analyses activities within these two studies focused on evaluating the late Holocene climate variability of the ostracode and pollen stratigraphic records (referred to as proxies for climate records) from southern Pahranagat Lake. These high-resolution records will serve as analogs to aid in interpretation of the earlier Holocene and late Pleistocene records. The combined study dealt with 128 samples from 5 m of lake sediment collected in two overlapping cores. Pollen and ostracodes were extracted from sample splits and the paleohydrological and paleoclimatic results obtained with each proxy compared. The two data sets include counts of over 60,000 pollen grains and over 22,000 ostracode valves. This effort is a major accomplishment because it shows that environmental reconstructions using different types of proxies are similar. The general results from this effort, reported below in the respective activities, are still preliminary and will be analyzed further in the coming months.

A second major accomplishment involves the radiocarbon results from the chronological study conducted by geologists at the University of Arizona. That study sought to evaluate the accuracy of the radiocarbon ages obtained from various mollusks found in the marsh deposits surrounding Yucca Mountain. The initial data from that study suggest, by comparison with associated organic matter, that certain species of mollusks provide reliable ages but others give ages that are too old (see Activity 8.3.1.5.1.2.2).

A third major accomplishment was the organization of a climate symposium at the 5th Annual International High-Level Radioactive Waste Management Conference in Las Vegas, Nevada, May 22-26, 1994. Topics covered in the 13 talks ranged from modern precipitation styles, to reconstruction of past climate states from fossil studies, to reconstruction of past ground water hydrology at both regional and site scales, and to paleoclimate-record-based validation of climate-model computer codes. Collectively, the data presented from Studies 8.3.1.5.1.2 and 8.3.1.5.1.3 suggest that the late Pleistocene climate in the vicinity of Yucca Mountain likely underwent substantial change on a short term, perhaps century, scale. Those changes resulted in dramatic climate change from episodes

characterized by cool (cold?) temperatures and likely low levels of precipitation to episodes that were much wetter and were characterized by cool summers. These changes appear to be related to the average position of the polar jet stream and likely the subtropical jet stream relative to Yucca Mountain. During these episodes the local valleys contained wetlands of various sizes and regional ground water levels rose. When refined, these results will be applied to the assessment of repository performance.

The fourth accomplishment comprises the extensive dating of climatic indicator plant species from ancient woodrat middens (Activity 8.3.1.5.1.3.1). This activity entails the direct dating of climatically sensitive plant species remains from woodrat midden strata to date their occurrence at specific localities and times in the past and to verify the association of various plant species within particular woodrat midden strata. During this process both new and old collections of ancient woodrat midden strata are being dated with the accelerator mass spectometry to confirm previous age assignments and associations of plant species. These confirmations will allow more accurate reconstructions of past climates, when these past reconstructed plant communities are compared with the distribution and climates of the same plant species today. This work provides an independent check on paleoclimate as reconstructed from the aquatic record.

Finally, faunal and water samples were collected from Pahroc and nearby springs, located between Alamo and Caliente, Nevada, and about 30 km from Yucca Mountain. These samples were collected to examine water quality, stable isotope characteristics, and ostracode species of modern perched springs in fractured volcanic rocks in order that these data may be compared with the Pleistocene and earlier Holocene data collected elsewhere in the area. Mean annual precipitation for Pahroc Spring is not known, but at Caliente it is about 300 mm or about twice that of Yucca Mountain. The analyses of these samples are discussed under Activity 8.3.1.5.1.2.2.

Activity 8.3.1.5.1.2.1 - Paleontologic analyses. The objective of this activity is to assemble and interpret, in paleoclimatic terms, detailed records of ostracodes, diatoms, and pollen, along with other types of fossils as warranted by specific paleoclimatic questions.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.5.1.2.2 - Analysis of the stratigraphy-sedimentology of marsh, lacustrine, and playa deposits. The objectives of this activity are to identify and characterize the general physical and chemical properties of sedimentary units from outcrops, shore deposits, and cores (this information will provide a physical and relative temporal framework within which various paleoenvironmental studies will be made); and to determine the specific environment of deposition for the sedimentary units using the principles of clastic and chemical sedimentology.

Ostracodes extracted from 128 samples of 5 m of core taken from the southern Pahranagat Lake were counted by species and the data entered into a spreadsheet for analyses. Initial interpretation of the data indicates that during the last two or three thousand years, lake volume has varied greatly and, at times, the lake has shrunk to a spring-supported marsh.

This interpretation indicates climate varies within the modern style of atmospheric circulation to states of higher- and lower-than-modern levels of effective moisture.

Stable isotope data have been analyzed from numerous biogenic carbonate and ostracodes samples collected from late Pleistocene sediments deposited in wetlands on the upper Las Vegas valley floor. Initial analyses of that data, reported in part in the climate symposium at the 1994 High-Level Waste Conference, indicate late Pleistocene atmospheric circulation resulted in increases in effective moisture due to episodes of increased mean annual precipitation and of reduced mean annual temperatures. The duration and magnitude of the mean annual precipitation and mean annual temperature values must be determined and verified, but imply those climate conditions likely supported infiltration, percolation, and recharge at Yucca Mountain. These findings will be considered in the assessment of ground-water travel time and repository performance.

A chronological study was conducted to evaluate the accuracy of the radiocarbon ages obtained from various mollusks found in the marsh deposits surrounding Yucca Mountain. The initial data from 73 radiocarbon analyses of mollusks suggest, by comparison with radiocarbon dates from associated organic matter, that certain species of mollusks provide reliable ages but others give ages that are too old. Those yielding reliable dates are known from the Pleistocene wetland deposits throughout the region, so those deposits can now be reliably dated. Understanding the age distributions, together with the spatial distribution and paleoenvironmental reconstructions, of ancient wetlands will allow the environmental events to be compared with other records ranging from those at Devils Hole to global insolation values. These comparisons will provide hydrological models with appropriate magnitudes of mean annual precipitation and temperature changes for suitability or performance assessment considerations.

Ostracodes recovered from modern day Pahroc Spring in July 1994 were, in general, not found in the late Pleistocene springs that discharged from the alluvial fans along the Pahrump and Las Vegas valleys. The stable-isotope data derived from water samples suggest Pahroc Spring is supported by winter precipitation. The taxa in the late Pleistocene springs imply water temperature was colder than modern day Pahroc Spring. Because discharge temperatures of shallow springs approximate mean annual temperature, these results support other climate reconstructions, including those of Spaulding (1983), that indicate colder mean annual temperatures during the late Pleistocene. The data may be useful in understanding perched water encountered in USW UZ-14 and the potential effect of increased mean annual precipitation on ground water discharge in the vicinity of Yucca Mountain.

Activity 8.3.1.5.1.2.3 - Geochemical analyses of lake, marsh, and playa deposits. The objective of this activity is to provide a detailed chemical and mineralogic characterization of lacustrine, marsh, and playa deposits to generate information about paleohydrology, sediment provenance, weathering rates, and sediment-water interface environments in ancient lakes.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.5.1.2.4 - Chronologic analyses of lake, playa, and marsh deposits. The objective of this activity is to obtain an accurate chronologic framework for the paleoclimatic information acquired in this study. All age information should, whenever possible, be tested with other techniques to reduce uncertainties.

No progress to report; this was an out-year activity.

Forecast: The USGS will continue to subsample the cores collected by Desert Research Institute from about a dozen lake, playa, and marsh deposits throughout the southern Great Basin to provide dates and ostracode assemblages for the deposits. Similar studies will be conducted on samples selected from a long core taken either from Sevier Lake in Utah, or from Death Valley by the USGS Global Change and Climate History program. These studies are closely integrated with those from the Terrestrial Paleoecology activities (Study 8.3.1.5.1.3).

3.4.3 Study 8.3.1.5.1.3 - Climatic Implications of Terrestrial Paleoecology

The objective of this study is to provide quantitative estimates of changes in climatic variables (precipitation, temperature, seasonality, etc.) for late Quaternary time in the southern Great Basin. This study will collect and analyze data on plant macrofossils from pack rat middens; fossil pollen assemblages from lake, marsh, and playa deposits; radiocarbon age determinations on paleovegetational assemblages; vegetation-climate and/or pollen-climate response surfaces; and pollen climate transfer functions.

The DOE has committed grant monies to the Desert Research Institute, University of Nevada, Reno, to support independent research that includes paleoclimatic tasks specified in parts of the Site Characterization Plan. Desert Research Institute has agreed to follow USGS quality-assurance techniques in its studies, enabling USGS to use data collected by Desert Research Institute in its own studies.

Activity 8.3.1.5.1.3.1 - Analysis of pack rat middens. The objective of this activity is to determine nature, timing, duration, and magnitude of past vegetation changes as recorded in plant macrofossil assemblages preserved in pack rat middens.

The primary result within this activity was the analysis of about 40 radiocarbon samples. The resulting ages provide a better understanding of the timing of vegetation migrations onto the valley floors of southern Nevada during the Pleistocene and of migration of plants up and down slope during the Holocene. Results from stable carbon isotope analyses of plant material from middens suggests that this method may provide a relative estimate of the plants' "water stress" and thus an indication of available water for infiltration and recharge. This variable is one of the most difficult to evaluate in development of hydrologic models.

Results thus far indicate two important conclusions. First, there were apparently two periods during which white fir descended to lower elevations; this had only been hinted at in

previous woodrat midden data from southern Nevada. Centered around 24,000 and 13,000 years before the present, these periods coincided with high lake stands recorded from other portions of the Great Basin. Second, results from the ^{13}C analyses strongly suggest that temperature is a strong driver of water stress in plants during approximately the last 40,000 years. Short-term enrichment in plants of ^{13}C are, as has been generally assumed, physiologically driven by reductions in rainfall. However, long-term enrichment in plants of ^{13}C are apparently the result of lowered temperature.

Activity 8.3.1.5.1.3.2 - Analysis of pollen samples. The objective of this activity is to determine the nature, timing, duration, and magnitude of past vegetation change as recorded in the stratigraphic record of fossil pollen grains.

Pollen extracted from the 128 samples from 5 m of core taken in the southernmost Pahranagat Lake was counted. The detailed results of that high-resolution data set (over 60,000 grains) are just now being tabulated, but the preliminary results show substantial changes in the terrestrial vegetation community in the Pahranagat Valley during the period spanning only the last two or three thousand years. For example, the abundance of juniper increases and decreases several times, indicating the quantity of winter precipitation has increased and decreased significantly. Conversely, there are periods when juniper abundance was low and certain grasses were common, indicating that summer precipitation became available during some periods when winter precipitation waned. The increase and decrease in winter (summer) precipitation is likely due to decadal to century scale variations in the position of the polar and subtropical fronts and illustrates that even in the seemingly invariant late Holocene climate has changed rather dramatically.

The pollen indicators of winter vs. summer precipitation, when compared with pollen from emergent versus submergent aquatic plants, shows lake expansion with winter precipitation and contraction with summer precipitation. This result is in good agreement with the ostracodes identified from the same samples and indicates the pollen and ostracode records are recording different aspects of the region's hydroclimatology.

Pollen data from the Pahranagat lakes and elsewhere in the Great Basin suggest that, during the late Holocene, winter moisture increased and was associated with expansion of marshes and increased spring discharge at 3,600 years BP, from 2,300 to 1,900 years BP, at 1,000 years BP, and about 350 years BP. This information is generally corroborated by long-term tree-ring data and also by the ^{13}C enrichment curve from the woodrat midden materials. These results demonstrate that climate variations during the next 10,000 years may have a more profound effect on local and regional hydrology than had previously been appreciated.

A manuscript describing the results of the study has been prepared (Forrester et al., in prep.) and is being reviewed. This manuscript is the first step to synthesize the terrestrial vegetation records into climate terms that can be used by the YMP.

A vertebrate data base for calibrating various aspects of the vertebrate fossils in climate terms has been constructed, but has not been mapped.

See Activity 8.3.1.5.1.2.2 for additional progress in this study.

Activity 8.3.1.5.1.3.3 - Determination of vegetation-climate relationships. The objective of this activity is to translate vegetational records provided by pack rat midden and palynological activities and available dendroclimatological data into quantitative estimates of past climatic variables.

No progress during the reporting period; this was an out-year activity.

Forecast: During FY 1995 these studies will proceed, using both paleontologic and isotopic records to identify climate change in southern Nevada. They will be closely integrated with the lakes, playas, and marshes activities in Study 8.3.1.5.1.2.

3.4.4 Study 8.3.1.5.1.4 - Analysis of the Paleoenvironmental History of the Yucca Mountain Region

The objectives of this study are to evaluate the paleoenvironmental record at Yucca Mountain and surroundings in light of inferred paleoclimate history of the southern Great Basin; to provide information to distinguish the effects of surficial processes from those of tectonic activity, based on the character and distribution of surficial deposits; and to evaluate the age of tectonic events.

In response to the recognition of the need for defensible numerical ages for Quaternary deposits, a proposal to provide a comprehensive and integrated geochronological investigation of surficial deposits was submitted to DOE. The lack of calibrated materials and the application of nonstandard dating techniques in the past present distinct problems for evaluating the existing ages used to estimate erosion rates, faulting kinetics, and climate-influenced sedimentation and soil-forming processes. The proposal was developed as a collaborative effort between USGS and Lawrence Berkeley Laboratory geochronologists, and USGS Quaternary geologists with input from DOE as to the Program needs.

A primary goal of this work is to apply a broader range of geochronological techniques most likely to provide useful data (uranium-series disequilibrium, luminescence, cosmogenic nuclide, tephrochronology, and radiocarbon methods) to several well-characterized Quaternary deposit profiles. Evaluation of the numerical dating results will be based on both internal consistency checks using stratigraphic and geologic controls, as well as on external consistency checks between different independent chronometers applied to the same deposits. Sites will be chosen on the basis of representing important surface deposits along with a consideration of the materials available for dating at each site. Data on the physical properties of the soils at each of the sites will also be collected. A longer-term goal of this investigation is to evaluate the reliability of assuming an age for a surficial deposit based solely on its physical morphology. This evaluation is critical if soil properties will be used to predict deposit ages in a variety of physical settings.

Activity 8.3.1.5.1.4.1 - Modeling of soil properties in the Yucca Mountain region. The objectives of this activity are to determine the relations among properties of late Holocene soils and climatic parameters; to compare properties of selected soils at Pahute Mesa and near Tonopah, which formed under conditions similar to those that may have existed at Yucca Mountain during Pleistocene pluvial conditions; to compare postulated past climates based on properties of early Holocene and Pleistocene soils to paleoclimatic models that are reconstructed from other lines of evidence, such as paleolimnology and terrestrial paleocology, as a check on these models; to postulate past climates based on the depth, distribution, and quantity of pedogenic carbonate and other soil parameters; and to quantify rates of soil development in specific climates for use as a dating tool for Quaternary deposits and ages of fault movements.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.5.1.4.2 - Surficial deposits mapping of the Yucca Mountain area. The objectives of this activity are to determine the distribution, age, genesis, soil properties, and physical properties of surficial deposits in the Yucca Mountain area; to evaluate the influences of climate and tectonics on the genesis of surficial deposits; to provide a map of surficial deposits for facility placement planning, geomorphic studies, tectonics studies, engineering property studies, and surface infiltration studies; and to determine the distribution of major concentrations of calcite-silica deposits at or near the ground surface at Yucca Mountain.

The preliminary surficial deposits map of the northeast quarter of the Busted Butte 7.5-foot quadrangle (Lundstrom et al., in prep.) received USGS Director's approval in June 1994 after response to technical review. The map area includes extensive alluviated areas of Midway Valley, lower Yucca Wash, and Fortymile Wash adjoining Alice Hill and Fran Ridge. The surficial deposits of this area provide a record of regional (Fortymile Wash) and local (east slope of Yucca Mountain) landscape response to past history of climate and tectonics. The distribution and field characteristics of surface materials indicated by this map, including alluvial, colluvial and eolian soils, are also being used in studies of past, present and future water infiltration at Yucca Mountain, as a basis for spatial distribution of hydrologic properties. A digitized version of this map is being produced for its utility in subsequent data analysis and transfer, and report production. The data obtained during mapping provide an alternative method of calculating erosion during the Holocene and will be used to answer questions raised by NRC in their review of the Extreme Erosion Topical Report.

Using the stratigraphic framework developed for the above map, a preliminary surficial deposits map of the adjoining northwest quarter of the Busted Butte 7.5-foot quadrangle, which includes Yucca Crest and the area directly overlying the proposed repository, was through technical review received on September 19, 1994. Mapping of the southern part of the Yucca Mountain area began in August 1994 with combined fieldwork and airphoto interpretation.

A report by Lundstrom and Warren (1994) on late Cenozoic evolution of Fortymile Wash related to Late Miocene Volcanism was presented at the 1994 High-Level Waste

Conference. This report provides an analysis of lithologic provenance, and altitude distribution of alluvium (Lundstrom et al., in prep.) and volcanic units along Fortymile Wash in terms of regional volcanic history that constrains the timing of the establishment of Fortymile Canyon. The work has major relevance to long-term regional erosion history at Yucca Mountain and obviates the need for the current worse-case scenario for erosion.

The increasingly recognized need for defensible age control on surficial deposits, critical to issues involving the histories of climate, paleohydrology, tectonics and erosion, resulted in several internal meetings and one field review during this period, and a proposal for accelerated Quaternary geochronology studies of the area.

Analysis of U and Th isotopic compositions were completed for four samples from the upper and lower soil carbonate horizons in the Fortymile Wash high terrace gravel. Preliminary results indicate an excess of 230Th relative to 238U in the samples analyzed; this is most likely related to uranium loss. This situation does not allow estimation of 230Th/U ages until additional samples are analyzed.

Activity 8.3.1.5.1.4.3 - Eolian history of the Yucca Mountain region. The objectives of this activity are to document eolian erosion and deposition in the Yucca Mountain area during the last 750,000 years; to determine paleoenvironmental conditions during times of eolian deposition and intervening times of surface stability and soil formation; and to determine source areas of sand and silt.

No progress during the reporting period; this was an out-year activity.

Forecast: Mapping will continue in the adjoining central and southern map area, and reports for individual 1:12,000 quadrangles will be submitted for review as mapping is completed. Geochronological and pedologic investigations of mapped deposits will continue as necessary to provide critical constraints on geomorphic and tectonic rates and on the responses of the Yucca Mountain landscape to Quaternary climatic changes. A report will be prepared of a debris flow event in July 1884, and additional age dates obtained, to address NRC questions on the Extreme Erosion Topical Report.

Geochronological work will focus on alluvial and eolian deposits on both the east (Midway Valley and Fortymile Wash) and west (Fatigue Wash fault and Solitario Canyon Fault) sides of Yucca Mountain in FY 1995. Work planned for the first year will involve experimentation with available materials to establish the most reliable analytical techniques applicable to each of the dating methods. Data collected in this period will allow an initial evaluation of whether each of these dating methods provides useful information and whether each method is worth pursuing in the future. Dating results and soil property data for a limited number of sites will be compiled in the year-end report. The second stage of data collection (FY 1996) will broaden the study to additional sites. This work will focus on testing the reliability of correlating soil morphology and depositional age at different sites influenced by a variety of soil-forming factors.

3.4.5 Study 8.3.1.5.1.5 - Paleoclimate-Paleoenvironmental Synthesis

The objectives of this study are to compare paleoclimatic estimates from the various proxy data sets and to provide data syntheses in the formats required for future climate and paleohydrology investigations.

No progress during the reporting period; this was an out-year study.

Forecast: The study plan for this activity will be submitted to DOE for approval, and the synthesis will be started. A preliminary synthesis is scheduled to be completed in the second half of FY 1995.

Activity 8.3.1.5.1.5.1 - Paleoclimate-paleoenvironmental synthesis. The objective of this activity is to provide summaries of the paleoclimatic data in formats that can be utilized by investigations of future climatic changes and paleohydrology.

3.4.6 Study 8.3.1.5.1.6 - Characterization of the Future Regional Climate and Environments

The objective of this study is to estimate key climate parameters, including precipitation, temperature, and evapotranspiration, for the Yucca Mountain area over the next 100,000 years with special emphasis on the next 10,000 years.

Activity 8.3.1.5.1.6.1 - Global climate modeling. The objective of this activity is to provide boundary-condition data for regional climate models for a selected set of climate scenarios that may occur during the next 100,000 years.

A series of five reports produced by Pacific Northwest Laboratory, documenting earlier preliminary global modeling work, were received by YMSCO. Because of unresolved Quality Assurance questions regarding the work, the reports will be used in future work for information purposes only.

Activity 8.3.1.5.1.6.2 - Nested global-regional climate modeling. The objective of this activity is to embed higher-resolution regional climate modeling within global climate modeling and couple with soil-physics-hydrology model to develop capability to predict future climatic-induced conditions and net infiltration in the Yucca Mountain area.

Validation of the regional climate modeling code, RegCM2, acquired from the National Center for Atmospheric Research for use in this study, was completed to satisfy software QA requirements. The acquired code validation activity included placing a controlled version of the code under software configuration management, installing the code on a new operational platform (workstation rather than mainframe), testing performance of the acquired code against a test problem, and completing associated documentation, all of which are prerequisite to release of the code for Project use.

Two preliminary model validation exercises were completed during this period. These exercises compare the code modeling results with observations for two different climate states: the present climate state and a state that existed 21,000 years ago. These model validation exercises are important precursors to modeling future climate states, as they provide an indication of the extent to which code results reflect known natural system behavior. The preliminary paleoclimate model validation effort was particularly useful in demonstrating that the model was stable even under large changes in surface and perimeter boundary conditions that had not been previously exercised with the code. This very short simulation produced meteorologically plausible results and showed some promising agreement with paleoclimatic interpretations, and will be used to guide more extensive validation analyses with the nested codes. Reasonable agreement between the simulation and observations of the present-day climate of the current climate model validation was also obtained.

After the nested global and regional climate model codes have been validated, several more rigorous model validation activities will be performed to develop confidence in and a better understanding of the model's ability to represent natural system behavior. Simulations of potential future climate states will then be made with the fully validated codes and used in future climate synthesis activities, the results of which will be provided for use in postclosure performance assessments.

Activity 8.3.1.5.1.6.3 - Site-specific model output adjustment. The objective of this activity is to predict climatic parameters such as precipitation, soil moisture, and net-infiltration rates for several possible future-climate scenarios at Yucca Mountain.

In other work examining the spatial transformation of regional model results to a more site-specific scale, a process for relating regional model grid coordinates to the physical setting at Yucca Mountain was developed for use in post-processing regional model output. This effort is being conducted because the resolution of the regional climate model output is too coarse to adequately address local effects of climate on hydrology.

Activity 8.3.1.5.1.6.4 - Future climate synthesis. The objective of this activity is to analyze time-series data of climatic variability based on the paleoclimatic record to identify possible future scenarios of concern that may occur during the next 100,000 years.

No progress during the reporting period; this was an out-year activity. The forecast discusses plan for FY 1995.

Forecast: Efforts will continue to acquire and validate numerical climate modeling codes for use in modeling future regional climate. The GENESIS global climate modeling code will be entered into the software configuration management system and used to "nest" with RegCM2 (validated in FY 1994) to perform two analyses: one for current climate conditions and one for a late Quaternary climate state. Analysis of results will be included in a report for use in hydrology, ground-water travel time, and performance assessment modeling.

A preliminary synthesis will be prepared of the possible future climate for the Yucca Mountain region. The synthesis will represent a range of potential climate conditions that may occur and that could potentially impact repository performance. An attempt will be made, to the extent feasible, to provide bounding conditions for severe climate conditions that may impact performance.

3.4.7 Study 8.3.1.5.2.1 - Characterization of the Quaternary Regional Hydrology

The objective of this study is to characterize the distribution of surface water, the unsaturated zone infiltration and percolation rates, and the ground-water potentiometric levels during the Quaternary Period in the vicinity of Yucca Mountain.

Activity 8.3.1.5.2.1.1 - Regional paleoflood evaluation. The objectives of this activity are to identify the locations and investigate the hydraulic characteristics of paleoflood events and compare this evidence with the locations and characteristics of modern flooding and geomorphic processes; and to assess the character and severity of paleoflood and debris hazards and the potential of flood and debris hazards for the repository during the preclosure period.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.5.2.1.2 - Quaternary unsaturated zone hydrochemical analysis. The objectives of this activity are to determine the past and infiltration percolation history at Yucca Mountain by analyzing the isotopic and chemical characteristics of water from the unsaturated zone; and to understand the past unsaturated-zone hydrologic system by modeling vadose-water hydrochemistry to help predict the future hydrologic system.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.5.2.1.3 - Evaluation of past discharge areas. The objectives of this activity are to determine the location, type, and extent of hydrogeologic units in the ground-water discharge areas of the Amargosa Desert and Death Valley; to understand the past quantity and quality of water in the discharge areas of Franklin Lake, Amargosa Desert River, and Peter's Playa and to determine the paleohydrologic significance of Peter's Playa and Franklin Lake as discharge areas; to determine the location and hydrogeologic characteristics of paleospring deposits in the discharge area; to determine the location and amount of discharge by evapotranspiration that has occurred at past discharge sites; to understand the past and present discharge areas of the regional hydrologic system to predict the future saturated zone hydrologic system at Yucca Mountain; and to determine past ground-water levels in carbonate caverns as evidence of past hydrologic conditions.

Uranium (U) and thorium (Th) isotopic compositions were obtained on carbonate nodules and calcified plant material from the Horse Tooth Deposit (Highway 95 hydrogenic deposits). Samples are located stratigraphically above the prominent white diatom-rich bed. Preliminary $^{230}Th/U$ age estimates suggest that the site may have been saturated as recently as

12 ka, and constrain the open-water stage of the deposit to between 12 and 30 ka, a prominent period of high-water stands noted elsewhere throughout the Great Basin. Additional analyses are required before final age estimates can be obtained.

Peterman and Stuckless (1994) have shown that in the Yucca Mountain region, strontium isotopes of ground water vary systematically, with more radiogenic values occurring in the southern, distal portion of the flow system. Radiogenic strontium at Ash Meadows derives from interaction with Proterozoic rocks in the northwestern Spring Mountains, whereas radiogenic strontium in the springs in eastern Death Valley reflects either interaction with Proterozoic rocks in the Funeral Mountains or input from the upgradient volcanic and alluvial aquifer into the carbonate aquifer. Strontium isotopes provide a method for tracing the ground water flow paths that must be accurately determined for performance assessment of the potential repository at Yucca Mountain.

Samples from the Crater Flat and Horse Tooth deposits were analyzed for uranium and thorium isotopes by mass spectrometry. Samples of nodular carbonates were collected from a pit, hand-dug through a apparently young-looking mound to a depth of about 100 cm. An additional sample was collected from a prominent carbonate horizon below the diatomite-rich bed at the Horse Tooth deposit. Work continued on the chemical separation and purification of uranium and thorium from aliquots in this suite, and uranium and thorium isotope analysis by mass spectrometry is proceeding. Preliminary results indicate that most discharge-related carbonates have a relatively high amount of detrital thorium, most likely from the clay component of the eolian detrital fraction. These results indicate the need for additional analyses in order to obtain a multipoint mixing line before the age of the authigenic component can be reliably estimated.

An abstract by Mahan and Moscati (1994, in press) was prepared for presentation at the Geological Society of America Meeting held October 24-27, 1994, in Seattle, Washington. Both strontium isotopes and the stable isotopes of oxygen and hydrogen can be used to trace ground water flow paths. Water discharging from the southernmost springs at Ash Meadows has a distinct isotopic signature that can be correlated with springs discharging in the northwestern Spring Mountains. More radiogenic strontium in these waters derives from interaction with Precambrian and Cambrian clastic rocks exposed in the northwestern Spring Mountains. Heavier hydrogen compositions reflect recharge at relatively lower altitudes than most of the precipitation in the Spring Mountains. The majority of the discharge at Ash Meadows may result from recharge in the high Spring Mountains carbonate terrane; the recharge would then flow northward and then westward, around the northern Spring Mountains, avoiding interaction with the Precambrian and Cambrian clastic rocks.

Geochronologists compiled and processed presently available U-series disequilibrium data to provide age estimates for approximately 12 samples ranging from 12,000 to 120,000 years. Data are being incorporated into an open-file report by Paces et al. (in prep.). In this report, uranium-series disequilibrium, thermoluminescence, and radiocarbon dating techniques are being employed to assess the timing of hydrologic activity at sites of past water discharge south of Yucca Mountain. Preliminary results indicate that discharge was active during the late Pleistocene to as recently as 12,000 years before present. These results

indicate hydrologic activity that is at least an order of magnitude younger than previous estimates, although discharge may have been equally or more active at earlier times. A detailed reconstruction of the history of discharge at these sites is not yet possible, but will be required in order to answer important questions regarding the climate conditions that support reactivation of ground water discharge and to evaluate possible responses of the regional hydrology to future climate changes.

Uranium and Th isotopic analysis from three aliquots of a nodular carbonate from Crater Flat were completed; these samples were separated by differential settling of less than 400 mesh particles. The experiment was aimed at evaluating sedimentation of fines as a means of mechanically separating detrital clay components from authigenic carbonate components in this sample. Results did not fall on the same leach-residue line obtained previously, and imply additional sample and/or analytical complexities.

Uranium and Th isotopic data were obtained from three samples of banded travertine exposed at the surface on the Grapevine Springs tufa mound in Death Valley National Monument. Resulting data have not yet been reduced, but preliminary indications do not favor an interpretation of a late Pleistocene age.

Activity 8.3.1.5.2.1.4 - Analog recharge studies. The objective of this activity is to estimate the conditions and rates of ground-water recharge (infiltration) during the Quaternary Period in the vicinity of Yucca Mountain.

The BLM approved transfer of the right-of-way for the Kawich Basin study area from USGS to Desert Research Institute of the University of Nevada on May 5, 1994. The U.S. Forest Service allowed USGS access to the Stewart Basin study area with a formal permit. Desert Research Institute also is interested in this site and the Forest Service is investigating if continued operation of the site will impact an endangered subspecies of cutthroat trout that might potentially exist in the area.

Data collection at the arid-zone geochemistry site in Organ Pipe Cactus National Monument in Arizona was terminated and the equipment was turned over to the National Park Service. A report documenting meteorological data collection at the arid-zone site has been prepared (Riggs et al., in prep.). A report documenting soil horizons dating has been prepared (Beiling Liu, in prep.).

Activity 8.3.1.5.2.1.5 - Studies of calcite and opaline silica vein deposits. The objective of this activity is to determine the ages, distribution, origin, and paleohydrologic significance of calcite and opaline silica deposits along faults and fractures in the vicinity of Yucca Mountain.

Three sessions were organized for the 1994 High-Level Waste Conference. Topics covered in the 13 talks ranged from modern precipitation styles, to reconstruction of past climate states from fossil studies, to reconstruction of past ground water hydrology at both regional and site scales, and to paleoclimate-record-based validation of climate-model computer codes. The $CaCO_3$.SiO_2 activity was involved in four presentations by Sharpe et al.

(1994), Whelan et al. (1994), Vaniman and Whelan (1994), and McConnaughey et al. (1994). Strong arguments for deposition of the secondary calcite in the unsaturated zone at Yucca Mountain under conditions comparable to the present were made by Roedder et al. (1994), also at the 1994 High-Level Waste Conference. This conclusion places important constraints on understanding the hydrology of the unsaturated zone as it relates to performance assessment.

Efforts continued to define the relevance of pedologic processes to the geochemistry of infiltrating ground waters and the effects of different climate states on this system. Monitoring of the soil gas/fluid sites at Pagany Wash, Fortymile Wash, U.S. Ecology (Beatty), Fran Ridge, Holmes Road, and the top of Rainier Mesa continued; laboratory experiments to determine the best way of determining soil moisture content and its δD and $\delta^{18}O$ values were begun.

Oxygen-18 isotopic studies of opal/chalcedony/quartz from the Yucca Mountain area were begun. Including standards, stable isotopic compositions of about 310 carbonate and water, and about 180 soil gas CO_2 samples were determined. The preliminary data show that the opal in the soils and on fractures in the unsaturated zone is compatible with low-temperature formation conditions comparable to those of the present day, but that the quartz and chalcedony formed in the unsaturated zone and saturated zone were likely deposited much earlier and from fluids of widely varying $\delta^{18}O$ and/or temperature (some of the quartz/chalcedony samples came from the about 10.5 Ma "hydrothermal" event associated with the Timber Mountain caldera formation).

Isotopic studies of regional ground waters show that these isotopes apparently distinguish between flow systems originating well to the north (and discharging in those springs of the northern Ash Meadows spring line) and a relatively shorter flow system originating in the Spring Range and dominating discharge at several springs in the southern portion of the spring line.

Marshall and Mahan (1994) describe strontium isotope data that bear on the origin of the widespread calcretes and fault infillings in the Yucca Mountain region. Studies of soil carbonate from alluvial fans help constrain a model for the origin of soil carbonate that relies on a dominant eolian source. Some other component or past variation in the strontium composition of the eolian source is required to model the pedogenic carbonate system.

Marshall et al. (1994) describe the strontium isotope compositions of calcite fracture coatings sampled from drill core and then compare to those from surficial calcite and to perched water pumped from a drillhole in the unsaturated zone. With the exception of fracture calcites within 90 m above the water table, the unsaturated zone fracture calcites contain strontium similar to that in the soil carbonate. This indicates that downward flow, perhaps episodic, could form these fracture coatings. Perched water has a similar strontium signature indicating its separation from the regional ground water. Also, the isotopic signature of an altered zone within the Topopah Spring Tuff is consistent with a perched water source for the strontium. These data are important for reconstructing the history of the unsaturated zone and predicting its future as it relates to future transport of radionuclides.

In a continuing effort to utilize the best available analytical methods, geochemists revised the procedures used for the measurement of uranium and thorium isotopes. This revision incorporates both alpha-decay counting and mass-spectrometric determination of uranium and thorium isotopic compositions on authigenic materials and on water samples. It also integrates spike calibration along with instrument calibration which should eliminate the need for a separate technical procedure on spike calibration in the future.

Forecast: The analog recharge activity is concluded for the present time and will not be reinitiated unless DOE determines that further information is required.

Data and preliminary interpretations will be reported in progress reports during the latter half of FY 1995 for ongoing studies of (1) the secondary calcite and opaline silica within Yucca Mountain and at post-discharge sites, (2) the wide variety of silica phases within Yucca Mountain, and (3) the soil gas/fluid studies. Preliminary U-series dating of secondary calcite within Yucca Mountain should begin during FY 1995. Additional data will be obtained from the paleodischarge sites.

The results of ground water studies will be presented at the Fall Geological Society of America Meeting (Mahan and Moscati (1994, in press). Efforts are under way to expand this data set with samples from other wells and springs, with the hope of more clearly defining flow paths and possibly estimating ground-water travel times within the deep carbonate aquifer. The preliminary results of silica studies will be presented at the Fall Geological Society of America Meeting by Moscati and Whelan (in press). This study will be expanded in collaboration with Los Alamos.

3.4.8 Study 8.3.1.5.2.2 - Characterization of the Future Regional Hydrology Due to Climate Changes

The objective of this study is to characterize impacts of potential future climate changes on site unsaturated zone hydrology and regional and site surface-water system and saturated-zone hydrology.

Activity 8.3.1.5.2.2.1 - Analysis of future surface-water hydrology due to climate changes. The objectives of this activity are to simulate past changes in runoff and surface-water storage (lakes) resulting from past climatic change; and to use the relationship between paleoclimate and paleosurface-water conditions to predict the impact of future climatic conditions on the surface-water hydrology at the site.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.5.2.2.2 - Analysis of future unsaturated zone hydrology due to climate changes. As reported in Site Characterization Program Baseline, Revision 9, this activity has been deleted; the scope of work for this activity will be performed in Activity 8.3.1.2.2.9.5.

Activity 8.3.1.5.2.2.3 - Evaluation of possible future changes of the climate and regional geologic framework on the regional saturated zone hydrology. The objectives of this activity are to reconstruct paleohydrologic conditions at Yucca Mountain and use these conditions together with the paleoclimatic conditions reconstructed as a basis to predict the impact of future climatic conditions on the saturated-zone hydrologic system; to synthesize the existing paleohydrologic data through the use of numerical simulation techniques to determine effects that greater recharge would have on water-table altitude, ground-water flow paths, and hydraulic gradients between Yucca Mountain and the accessible environment; and to evaluate possible regional tectonic and thermal events that may produce prolonged or transient effects on the regional water level.

No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

3.5 EROSION (SCP SECTION 8.3.1.6)

The Extreme Erosion Topical Report has been reviewed by NRC, and nine comments were provided. A plan, involving minimal new work, has been developed to provide supplemental responses to the NRC comments.

Forecast: The DOE plans to provide supplemental responses to the nine comments provided by NRC. As a result of the study plan work scope consolidation effort, there are no study plans to be developed in this program. Any additional work needed to respond to NRC's comments on the Extreme Erosion Topical Report will be performed under Study Plan 8.3.1.5.1.4, "Analysis of the Paleoenvironmental History of the Yucca Mountain Region," under its existing work scope. The Site Design and Test Requirements Document will be revised to delete this program.

3.6 POSTCLOSURE TECTONICS (SCP SECTION 8.3.1.8)

3.6.1 Study 8.3.1.8.1.1 - Probability of Magmatic Disruption of the Repository

The objective of this study is to assess the probability of future volcanic activity with respect to siting of a potential repository for the storage of high-level radioactive waste at Yucca Mountain.

Activity 8.3.1.8.1.1.1 - Location and timing of volcanic events.The objective of this activity is to synthesize the data collected by other activities on the dating, location, and volume of late Cenozoic volcanic events in the region surrounding the site.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.1.1.2 - Evaluation of the structural controls of basaltic volcanic activity. The objective of this activity is to investigate the time-space patterns of past volcanic activity in the Yucca Mountain region and the possible structural controls of volcanic centers and potential future centers at and adjacent to Yucca Mountain.

Project volcanologists assessed multiple structural models of the probability of magmatic disruption of the repository, controlled area, and the Yucca Mountain region. Following the assessment they concluded that structural models incorporating northwest or northeast trends of the distribution of volcanic events do not lead to significantly different estimates of the disruption probability and the probability of disruption of the repository is a low probability event that has limited sensitivity for site disqualification.

Activity 8.3.1.8.1.1.3 - Presence of magma bodies in the vicinity of the site. The objective of this activity is to review geophysical and geochemical data collected in the vicinity of the site to assess whether there are any indications of the presence of crustal magma bodies that could be the source of future volcanic activity.

Reviews of the application of geophysical and tectonic models of the Yucca Mountain region to volcanism studies were provided by George Thompson, Stanford University. He consulted with the USGS on the anticipated results of the FY 1995 seismic reflection/refraction line across Crater Flat and on assessment of tectonic models of the origin of Crater Flat. An experiment was developed for obtaining aeromagnetic data for the Half Pint range. The data from this survey will be used to assess the depth of detection of basalt intrusions using aeromagnetic and ground-magnetic data. A scientific exchange was held with participants at the University of Nevada, Reno, on application of teleseismic results from the Yucca Mountain seismic net to the volcanism program. The preliminary results of the geophysical review were that sufficient geophysical data should be obtained from the seismic reflection/refraction experiment and the upgraded seismic net to further assess the possible presence of magma bodies in the subsurface of the Yucca Mountain region, and no further geophysical studies would be required, pending the results of ongoing and planned geophysical work. This review of the geophysical program was a direct response to written comments and questions by the NRC concerning the integration of geophysical and volcanism studies

Activity 8.3.1.8.1.1.4 - Probability calculations and assessment. The objective of this activity is to revise the estimates of the probability of volcanic disruption of a repository site at Yucca Mountain incorporating newly acquired data on the age, location, and volume of volcanic centers in the Nevada Test Site region and the results from activities investigating the possibility of structural controls of sites of volcanic activity and the presence of magma bodies in the Yucca Mountain area. These data may result in modifications of the area ratio and the rate of volcanic activity used in the probability formula.

A report by Crowe et al. (in prep.) describes volcanism work since 1978 for this study plan and Study Plan 8.3.1.8.5.1. The results of ongoing work are detailed, current to May 1994. The report presents the results of field, geochronology, and geochemistry data for

Miocene and younger basaltic volcanic centers of the Yucca Mountain region. The major conclusions are as follows:

1. Revised probability calculations were completed for volcanic recurrence rates, the probability of disruption of specified areas, and the probability of magmatic disruption of the repository. Simulation modeling was completed ahead of schedule to evaluate the sensitivity of alternative approaches to estimating the probability of magmatic disruption of the repository, the controlled area and the Yucca Mountain region. This modeling shows that midpoint estimates of recurrence rates are not significantly different nor are the results of probability estimates using different distribution models of the recurrence rate (homogeneous vs. nonhomogeneous Poisson models).

2. Field, stratigraphic, geochronologic and geochemical data were presented from the Lathrop Wells volcanic center. The results strongly indicate that the center is polycyclic with an eruption history that encompasses the last 100,000 years. If this interpretation is correct, the probability that any new volcanic eruption in the Yucca Mountain area during the next 10,000 years will occur at Lathrop Wells, is greatly increased.

3. The results of revised geochronology studies of the Quaternary basalt centers of Crater Flat are described using newly obtained $^{40}Ar/^{39}Ar$ total fusion results. These data constrain the age of individual centers with a precision of about 100 ka, which meets the geochronology requirements for these centers for probabilistic assessments. The cuttings from a basalt in an exploration drillhole in the Amargosa Valley were dated by the $^{40}Ar/^{39}Ar$ method. Results show that the buried basalt body responsible for an aeromagnetic anomaly is Pliocene, and about the same age as the 3.7 Ma basalt centers of southeastern Crater Flat. The Pliocene age verifies that this volcanic event does not result in significant modifications to the record of volcanism and has minimal effect on probabilistic assessment.

The results presented in the Volcanism Status Report (Crowe, et al., in prep.) provided the basis of a presentation on characterization of volcanic features, probability studies and effects studies to the NRC ACNW meeting in Bethesda, Maryland, on April 20, 1994.

Forecast: Alternative structural models will be developed for the distribution of past basaltic centers. These models will use constrained probability ranges of E_2. Stochastic and simulation modeling of spatial and structural models of E_2 will be performed. Data from field geologic studies and from aspects of the tectonics programs (seismicity, geophysical studies, studies of Quaternary faulting and fault systems, and the evaluation of tectonic models) will be used.

Review of the geophysical data for the Yucca Mountain region will continue and results will be evaluated to determine whether it is sufficiently comprehensive to allow adequate evaluation of the presence of magma bodies in the region. If there is evidence of the presence of subsurface magma in the Yucca Mountain region, detailed plans will be

developed for evaluating the existence and location of magma using geophysical data. Modeling of aeromagnetic data will be implemented to assess the issue of delectability of igneous intrusions.

Refined methods and calculations of the first t parameters of the three-part probability calculation will be developed. An iterative approach will be implemented using multiple alternative models for establishing the recurrence rate of volcanic events (E_1), similar to the approach used for establishing E_2. The first iteration of a data matrix of recurrence calculations has been completed using homogeneous and nonhomogeneous Poisson recurrence models, and refinement of these calculations has continued since then. Data will continue to be gathered for the final report on the probability of magmatic disruption of the repository, which is due in FY 1997, and with probability modeling of polycyclic eruptions. Work in this Work Breakdown Structure will also be evaluated in the Expert Judgment Report, due in late FY 1996.

3.6.2 Study 8.3.1.8.1.2 - Physical Processes of Magmatism and Effects on the Repository

The objective of this study is to gather data on the effects of a potential volcanic eruption should such an eruption penetrate the site. The data will be used to assess the consequences of such an eruption on repository performance.

Activity 8.3.1.8.1.2.1 - Eruptive effects. The objective of this activity is to summarize the effects of hydrovolcanic and Strombolian eruptions of basaltic magma on a repository. The summary will be available for use in consequence analyses of possible radiological releases.

Project volcanologists made major advances during this period. The first set of natural analog studies of xenolith abundances was completed at the Lucero volcanic field in New Mexico. The volcanoes in this region are of similar composition to those at Crater Flat, and exhibit similar eruptive facies ranging from purely magmatic to hydromagmatic deposits. Additionally, the stratigraphy of rock units below the volcanoes is very well known due to a combination of outcrop exposure and petroleum well logs. Xenoliths found in the eruptive units can therefore be correlated with their depth of origin, and from this the rate at which wallrock material is entrained into erupting magmas can be estimated. This information can be used in turn to estimate the quantity of radioactive debris which could be brought onto the Earth's surface through a volcanic eruption that penetrated the potential repository. Total xenolith volume fractions were reported by Valentine et al. (in prep.[a]). Valentine and Groves (in prep.) indicate that within the uppermost 700 m of the crust, xenolith entrainment depends largely on the mechanical properties of the wall rock.

Activity 8.3.1.8.1.2.2 - Subsurface effects of magmatic activity. The objective of this activity is to evaluate the subsurface effects of emplacement of basalt dikes and intrusive bodies through and adjacent to a potential repository. This study will include an assessment of mechanisms of incorporation of waste in magma, the geometry of basalt intrusions, and coupled effects on waste isolation of basalt intrusions through or near a repository.

Subsurface effects studies focused on two aspects. First, initial geochemistry and mineralogy sampling and analyses were carried out at the Paiute Ridge intrusive complex, located at the eastern edge of the Nevada Test Site. In addition to constraining the effects of basaltic intrusions on the hydrologic and transport properties of tuff host rocks, these data will be used for analog studies of repository thermal loading. A collaboration was initiated with the University of Texas-Austin on using simple rock properties such as density to estimate the hydrologic properties of tuffs. This information will be used in modeling the long-term effects of intrusions on the hydrologic flow field at a repository. Modeling studies of the spatial and temporal scales of various hydrothermal processes continued. Most work focused in vapor phase transport, which is expected to have the largest spatial scale and therefore will affect our estimates of probability of disruption of the potential repository. Initial calculations are reported by Valentine et al. (in prep.[a]).

Activity 8.3.1.8.1.2.3 - Magma system dynamics. The objectives of this activity are to evaluate the dynamics of basaltic magmatism including tracing the processes of formation of basalt magma through generation in the mantle, ascent through the mantle and crust, potential storage in the mantle and crust, and eruption at the earth's surface. Physically- and mathematically-based models of basaltic processes will be developed as a framework for a process-based assessment of the effects of basaltic magmatic activity on a repository.

Valentine et al. (in prep.[b]) describe factors that determine the geometry of intrusions at shallow depths in a paper that was prepared and submitted to the Journal of Geophysical Research. Based on observations at the Paiute Ridge intrusive complex, YMP volcanologists identified the importance of local fault locking and stress perturbations on whether a dike will feed a lateral intrusion (sill) or not. This is important information because the planform of an intrusion strongly influences the type of hydrothermal activity that may accompany it. This is significant because hydrothermal activity in the potential repository could compromise waste containment.

Forecast: Studies of xenolith entrainment (as an analog for repository waste entrainment) at small basaltic centers will continue. Data will be gathered at the volcanoes of the Crater Flat volcanic field near Yucca Mountain, and scoria cones, maars, and lava flows from selected centers in the San Francisco volcanic field (Arizona). Data collected during FY 1993-94 from the Luceor volcanic field (New Mexico) will be compiled, analyzed, and reported in a peer-reviewed journal publication. Results will be incorporated into probabilistic risk calculations. Work will continue on the subsurface effects of intrusion of magma at or near a potential repository. Modeling studies will focus on determination of the maximum spatial and temporal extent of hydrothermal (including vapor phase) circulation and will include three-dimensional calculations with Yucca Mountain geometry and hydrologic properties, and arrange of intrusion geometries. Modeling studies directed at understanding field data from analog sites will also be initiated. Field studies will concentrate on intrusion-induced variations in mechanical and mineralogical properties of tuff host rocks. Work will be initiated on tying geochemical, isotopic, petrologic, geophysical, and geochronological data for Pliocene- Quaternary-magmatism in the Yucca Mountain region with existing theoretical models of melt segregation, ascent, storage, and eruption.

3.6.3 Study 8.3.1.8.2.1 - Tectonic Effects: Evaluations of Changes in the Natural and Engineered Barrier Systems Resulting from Tectonic Processes and Events

The objective of this study is to assess the probability and effects of tectonic processes and events that could result in adverse effects on waste package lifetime, average percolation flux rate over the repository, elevation of the water table, local fracture permeability, effective porosity, and rock geochemical properties.

The study plan and Site Characterization Program Baseline were revised to combine Investigations 8.3.1.8.2, 8.3.1.8.3, and 8.3.1.8.4 into one investigation (8.3.1.8.2), one study (8.3.1.8.2.1), and five activities (listed below, corresponding to the five studies formerly included in the three investigations). The reason for this consolidation was that much of the work assigned in the Site Characterization Plan to these investigations duplicated work in other studies, and the remaining work was sufficiently closely related and limited in scope to the extent that the planned work elements and the designated objectives and parameters can logically and appropriately be integrated.

As part of the study plan consolidation effort, work scope associated with Study 8.3.1.8.5.3, Investigation of Folds in Miocene and Younger Rocks of Region, will be transferred to this study in which it will contribute to assessing the tectonic processes affecting Yucca Mountain.

Activity 8.3.1.8.2.1.1 - Analysis of waste package rupture due to tectonic processes and events. The objective of this activity is to collect and synthesize data that can be used to assess the probability and effects of tectonic processes and events that could result in adverse impacts on waste package lifetime and performance.

A conceptual model of the relation between tectonism and volcanism in the Yucca Mountain region was developed. This model addresses factors that affect the probability of magmatic intrusion through the repository and is presented in an administrative report (Fridrich, et al., in prep.)

A scoping study of the effect of tectonic activity (principally faulting) on the hydrologic system at Yucca Mountain was begun. It is critical to first develop an adequate conceptual model of the hydrologic system that incorporates existing data and interpretations. The conceptual model relating to volcanism in the Yucca Mountain area specifically refers to factors that affect the probability of magmatic intrusion through the repository.

Activity 8.3.1.8.2.1.2 - Analysis of the effects of tectonic processes and events on average percolation flux rates over the repository. The objective of this activity is to produce analyses and assessments of the probability and effects of tectonic initiating events that may result in changes in the average percolation flux rate at the top of the Topopah Spring welded unit.

A scoping study of the effect of tectonic activity (principally faulting) on the hydrologic system at Yucca Mountain was begun. It is critical to first develop an adequate conceptual model of the hydrologic system that incorporates existing data and interpretations.

Activity 8.3.1.8.2.1.3 - Analysis of the effect of tectonic processes and events on changes in water-table elevation. The objective of this activity is to produce analyses and assessments of the probability that tectonic initiating events could result in significant changes in the elevation of the water table, changes in the hydraulic gradient, the creation of discharge points in the controlled area, or the creation of perched aquifers in the controlled area.

Activity 8.3.1.8.2.1.4 - Analysis of the effects of tectonic processes and events on local fracture permeability and effective porosity. The objective of this activity is to address possible changes in fracture permeability and effective porosity caused by tectonic events and processes.

The work scope described under Activity 8.3.1.8.2.1.2 also supports this activity.

Activity 8.3.1.8.2.1.5 - Analysis of the effects of tectonic processes and events on rock geochemical properties. The objective of this activity is to provide assessments of the initiating events related to local changes in distribution coefficients resulting from tectonic processes and events.

The work scope described under Activity 8.3.1.8.2.1.2 also supports this activity.

Forecast: In FY 1995 a scoping study, using computer modeling of the hydrologic system, will begin. Two researchers, a mathematician/hydrologist at Colorado University-Boulder, and a geochemist/computer modeler with USGS Menlo Park, have been contracted to do the computer modeling in FY 1995. The plan is to build a preliminary basic model that incorporates known hydrogeologic constraints on the Yucca Mountain area.

A collection of aeromagnetic data will begin to evaluate the sensitivity with which such data indicates the presence of concealed intrusions. This work will be tested on the Nevada Test Site at a location where intrusions can be seen at the surface. The results of this work will then be applied to evaluating the presence of concealed intrusions at Yucca Mountain. Minimal funding constrains efforts on hydrologic computer modeling, but plans are under way to build a basic model that incorporates known hydrogeologic constraints on the Yucca Mountain area.

3.6.4 Study 8.3.1.8.3.1 - Analysis of the Effects of Tectonic Processes and Events on Average Percolation Flux Rates Over the Repository

This study has been combined with Study 8.3.1.8.2.1.

Forecast: This study will be deleted in Progress Report #12.

3.6.5 Study 8.3.1.8.3.2 - Analysis of the Effects of Tectonic Processes and Events on Changes in Water-Table Elevation

This study has been combined with Study 8.3.1.8.2.1.

Forecast: This study will be deleted in Progress Report #12.

3.6.6 Study 8.3.1.8.3.3 - Analysis of the Effects of Tectonic Processes and Events on Local Fracture Permeability and Effective Porosity

This study has been combined with Study 8.3.1.8.2.1.

Forecast: This study will be deleted in Progress Report #12.

3.6.7 Study 8.3.1.8.4.1 - Analysis of the Effects of Tectonic Processes and Events on Rock Geochemical Properties

This study has been combined with Study 8.3.1.8.2.1.

Forecast: This study will be deleted in Progress Report #12.

3.6.8 Study 8.3.1.8.5.1 - Characterization of Volcanic Features

The objective of this study is to provide refined data on the age, location, eruptive models, and volume of young volcanic rocks in the vicinity of the site. These data will be used to refine the calculations on the probability of igneous or volcanic events occurring in the controlled area and penetrating the repository.

Activity 8.3.1.8.5.1.1 - Volcanism drillholes. The objective of this activity is to investigate the origin of four or five aeromagnetic anomalies found in Crater Flat and the Amargosa Valley. Data from this work will be used to refine probability calculations, to evaluate the tectonic setting of volcanic centers, and to test concepts of the temporal geochemical patterns of basalts in the Nevada Test Site region.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.5.1.2 - Geochronology studies. The objective of this activity is to establish the chronology of basaltic volcanism and the youngest silicic volcanic activity in the Yucca Mountain region. These data will be used to revise the recurrence rate of the volcanic probability calculations and to determine the age of cessation of silicic volcanic activity. Further studies are required for three topics: the age of the Quaternary volcanic events in the Yucca Mountain region; the age and eruption chronology of the youngest (<0.5 ma) volcanic event in the Yucca Mountain area; and the age of the youngest silicic volcanic activity in the

region with emphasis on the Black Mountain caldera or young silicic rocks that may be encountered in shallow volcanic drillholes.

Geochronology studies continued with the goal of completing the geochronology of all post-Miocene eruptive centers by the end of FY 1995. These data will form the framework for final probability calculations. Geochronology samples were collected from Crater Flat for $^{40}Ar/^{39}Ar$ analysis and Hidden Cone at Sleeping Butte for cosmogenic ^{3}He analysis. Results of $^{40}Ar/^{39}Ar$ for basalts of Crater Flat, Amargosa Valley and Thirsty Mesa were presented by Crowe et al. (in prep.). Progress in $^{40}Ar/^{39}Ar$ measurements of reheated sanidine from tuff xenoliths enclosed in eruptive units at Lathrop Wells and Little Cones and new ^{3}He measurements from Lathrop Wells were reported in a letter report (Perry et al., 1994a).

Activity 8.3.1.8.5.1.3 - Field geologic studies. The objective of this activity is to establish the field geologic relations and the eruptive history of basaltic volcanic centers in the Yucca Mountain region.

A final chronostratigraphic model was completed for the Lathrop Wells volcanic center using revised data from trenching, field, geochemistry, and geochronology studies. These results indicate that the Lathrop Wells center is polycyclic and has an extended eruption history of approximately 100,000 years. Aspects of this model are presented in papers by Crowe et al. (in prep.) and Perry and Straub (in prep.).

Activity 8.3.1.8.5.1.4 - Geochemistry of scoria sequences. The objective of this activity is to determine the geochemistry of scoria sequences of different ages at the Lathrop Wells center and older centers in the Crater Flat area. The models will be used to test geologic assumptions made for the probability calculations and the time-space tectonic model for the distribution of basaltic volcanism. In addition, the data on the geochemistry of the scoria sequences will also be used to correlate basaltic ash interbedded in trenches with their correct eruptive source.

Microprobe analyses were completed of mineral phases from representative eruptive units at Lathrop Wells. This activity completed the acquisition of geochemical data from Lathrop Wells. Major, trace-element, isotopic and mineral chemistry data were compiled for inclusion in the report by Perry and Straub (in prep.). Statistical analysis of geochemical data from the Lathrop Wells center shows that individual eruptive units are geochemically distinct. In detail, the differences in geochemical composition of eruptive units cannot be due to evolution of a single magma body. Instead, eruptive units represent independent and separate magma batches that ascended at a single location over a period of approximately 100,000 years, indicating that magmas in the Yucca Mountain region ascend at preferred eruption sites rather than randomly. If this conclusion of preferred eruption sites is correct, the probability of magma ascending near the potential Yucca Mountain during the next 10,000 years is decreased.

A paper covering field, chemical and geochronological evidence for polycyclic volcanism at Lathrop Wells was presented at the Eighth International Conference on Geochronology, Cosmochronology, and Isotope Geology (Perry et al., 1994b). The abstract

of this talk was published in the Proceedings of this conference. The authors presented geochemical evidence for multiple magma batches at Lathrop Wells.

Activity 8.3.1.8.5.1.5 - Geochemical cycles of basaltic volcanic fields. The objective of this activity is to determine the time-space geochemical variations of the volcanic fields of the southern Great Basin.

Sr, Nd, and Pb isotopic analyses continued to be gathered for post-Miocene eruptive centers in the Yucca Mountain region. These data will be used to constrain the magmatic evolution of the Crater Flat Volcanic Zone, with particular emphasis on determining whether magmatic processes are waxing or waning in the Yucca Mountain region. New isotopic results suggest that the 3.7 Ma basalts of Crater Flat are contaminated by upper crustal wallrock, which supports the hypothesis that a higher magma flux in the early volcanic history of Crater Flat was able to support high level magma chambers. This is significant because it indicates that basaltic flux rates through the crust in the Yucca Mountain region may be waning with time.

Forecast: $^{40}Ar/^{39}Ar$ dating of basalt will be completed for all post-Miocene volcanic centers. $^{40}Ar/^{39}Ar$ dating of sanidine from fused tuff xenoliths at the Lathrop Wells will be finalized. Paleomagnetic, geomorphic and soils analysis will be completed at selected volcanic centers. Trenching of volcanic units will be completed at the Sleeping Butte Centers and selected volcanic centers in Crater Flat. Maps of all post-Miocene (<5 million years) centers will be finalized.

Geochemical studies at Lathrop Wells will focus on petrological and isotopic studies of the basalt of Sleeping Butte and the 1 Ma and 3.7 Ma basalt of Crater Flat. Isotopic analyses of Sr, Nd, Pb will be obtained for these units. Instrumental neutron activation analysis data for a selected suite of trace elements will also be obtained. Major element data will be obtained by x-ray fluorescence. Petrological modeling of the isotopic and geochemical data will be conducted to examine alternative models of basalt petrogenesis. The results of the modeling will be used to test assumptions used in probability calculations. Basaltic ash exposed in fault trenches east and west of Yucca Mountain will be sampled and analyzed for major and trace-element chemistry in order to correlate these ashes with eruptive episodes at the Lathrop Wells volcanic center. Correlation of these ashes will constrain the timing of major paleoseismic activity near Yucca Mountain.

Integration of geochemical and isotopic data for all post-Miocene volcanic centers in the Yucca Mountain region will begin. Evaluation of the evolution of analog volcanic fields in the southwestern United States to determine whether characteristic time-volume-geochemical patterns can be used to predict patterns of future volcanic activity will continue.

Siting of the drillholes and interpretation and geochemical analysis of the core from one of the four aeromagnetic anomalies in the Yucca Mountain region will be coordinated.

3.6.9 Study 8.3.1.8.5.2 - Characterization of Igneous Intrusive Features

The objective of this study is to gather data concerning the presence of thermal anomalies in the area and data on the geochemical and physical effects of intrusions on the surrounding rock. The evidence for the presence or absence of thermal anomalies will be used as part of the evaluation of the presence of significant magma bodies in the area and their relation to the probability of future volcanic events.

Activity 8.3.1.8.5.2.1 - Evaluation of depth of curie temperature isotherm. The objective of this activity was intentionally omitted. The most current evaluation of curie temperature data shows that the technique yields results that are too ambiguous and are at a scale of detection too general to be useful for application at Yucca Mountain.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.5.2.2 - Chemical and physical changes around dikes. The objective of this activity was intentionally omitted. Data on the nature and extent of physical changes that may occur in the surrounding tuffs as a result of the intrusion of dikes or sills will be collected under Study 8.3.1.8.1.2.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.8.5.2.3 - Heat flow at Yucca Mountain and evaluation of regional ambient heat flow anomalies. The objectives of this activity are to compile and evaluate available heat flow data at and near Yucca Mountain, to assess the need for additional heat flow determinations, to collect additional thermal data from existing and planned drillholes, and to identify and evaluate thermal anomalies.

Heat flow data and new interpretations of temperature and heat-flow measurements were summarized in a chapter of the Geophysics White Paper that is in process. Work on study plans for Activities 8.3.1.8.5.2.3 and related Activity 8.3.1.15.2.2.1 was completed with all comments generated during internal DOE review being resolved. The study plans were forwarded to NRC for their acceptance. All sondes, meters, balances, and related logging and laboratory equipment were maintained in a ready state in case there was a need to collect otherwise irretrievable data; no such need arose during the reporting period.

Forecast: This activity will not be funded in FY 1995. All work will be funded and performed within the closely-related Activity 8.3.1.15.2.2.1, surface-based evaluation of ambient thermal conditions.

3.6.10 Study 8.3.1.8.5.3 - Investigation of Folds in Miocene and Younger Rocks of Region

The objective of this study is to establish the regional pattern and rate of Neogene folding.

Activity 8.3.1.8.5.3.1 - Evaluation of folds in Neogene rocks of the region. The objective of this activity is to establish the pattern, rate, amplitude, and wavelength of post-middle Miocene folding in the region.

This Site Characterization Plan section contains one activity that relies on available data; no unique data is to be acquired.

Forecast: As a result of the study plan consolidation effort, there will be no study plan for this activity. Aspects of this work scope will be transferred to Study Plan 8.3.1.8.2.1. The Site Design and Test Requirements Document will be revised.

3.7 HUMAN INTERFERENCE (SCP SECTION 8.3.1.9)

3.7.1 Study 8.3.1.9.1.1 - An Evaluation of Natural Processes that Could Affect the Long-Term Survivability of the Surface Marker System at Yucca Mountain

The objective of this study is to provide information on the currently or potentially active natural processes at Yucca Mountain capable of adversely affecting the long-term survivability of the surface marker system. This study will be a synthesis of data obtained from other activities to be undertaken in support of several investigations. The data will then be evaluated to determine the most suitable locations of the monuments for the surface marker system.

This study is to identify candidate sites free of tectonic, seismic, volcanic, erosion, or depositional influences that would mitigate against survivability of surface markers. The two activities in this Site Characterization Plan section draw upon data collected from other studies. There are no unique data to be collected. Activity 8.3.1.9.1.1.1 will extract available data from Studies 8.3.1.8.1.2 and 8.3.1.8.2.1 to perform the assessment for marker siting. Activity 8.3.1.9.1.1.2 will use data reported in the Extreme Erosion Topical Report and related work such as surficial mapping and Study 8.3.1.5.1.4.

Activity 8.3.1.9.1.1.1 - Synthesis of tectonic, seismic, and volcanic hazards data from other site characterization activities. The objective of this activity is to identify the potential locations of faulting and volcanic eruption or intrusion that could occur where they could affect the marker system.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.9.1.1.2 - Synthesis evaluation of the effects of future erosion and deposition on the survivability of the marker system at Yucca Mountain. The objective of this activity is to determine the effects of future erosion and deposition on the topographic elements of the controlled area boundary at Yucca Mountain. This information will be evaluated to identify the optimum locations for the markers.

No progress during the reporting period; this was an out-year activity.

Forecast: There will be no study plan developed for this Site Characterization Plan section. A DOE working paper will be developed to recommend candidate locations for surface markers in the out years.

3.7.2 Study 8.3.1.9.2.1 - Natural Resource Assessment of Yucca Mountain, Nye County, Nevada

The objective of this study is to identify and assess the natural resource potential at the proposed repository site at Yucca Mountain. The information and data obtained in this study will provide the basis for probabilistic calculations for determining inadvertent human interference and intrusion.

Activity 8.3.1.9.2.1.1 - Geochemical assessment of Yucca Mountain in relation to the potential for mineralization. The objective of this activity is to conduct a geochemical sampling program to evaluate the potential for precious, base, and strategic metals; energy resources; and industrial mineral resources in the vicinity of Yucca Mountain. Specific objectives include selecting a suite of elements for analysis in a geochemical sampling program based upon known commodities that occur in silicic tuffs and/or trace elements indicative of commodities that occur in the tuffs, developing a field program to include a systematic and biased sampling of surface materials, generating a first-order geochemical data base for selected elements obtained from surface and subsurface sampling within the vicinity of Yucca Mountain, evaluating the data base in conjunction with geological and geophysical data obtained from other site characterization activities to determine if additional data are needed for an evaluation of natural resources, and evaluating the potential for the occurrence of natural resources in the vicinity of Yucca Mountain based on an analysis of the geochemical data.

A geochemical sampling program is under preparation by DOE. This sampling initiative includes surface and subsurface sampling and employs multiple analytical techniques. Appropriate levels of analytical detection will be the main focus of the analytical techniques selected.

During this reporting period samples have been collected and analyzed to be used for stratigraphic and geochemical variation studies of the pyroclastic rocks found at Yucca Mountain. These chemical analyses can also be considered in the natural resource assessment work. The geochemical analyses obtained by x-ray diffraction techniques are being compiled

and include sample locations, sample descriptions, and geochemical data. Several of these efforts have been published in this reporting period.

Peterman et al. (1994) report the strontium isotope compositions of Paleozoic carbonate rocks from Bare Mountain, southern Nevada. The strontium isotopic values were measured across a gold ore zone located at the Sterling mine for comparison with measured isotopic values found in Paleozoic carbonate rocks in borehole UE-25 p#1. This information may be used in the comparison of Yucca Mountain with surrounding regions in the evaluation of the resource potential of the site.

An open-file report by Neymark et al. (in prep.) compares geochemical and isotopic measurements in altered and unaltered sections of the Tiva Canyon Tuff and Topopah Spring Tuff. These formations form the uppermost portion of Yucca Mountain; the Topopah Spring Tuff is the potential host for the high-level radioactive waste repository. By comparing data from altered samples to more typical unaltered Tiva Canyon Tuff and Topopah Spring Tuff, the components introduced during alteration are identified as primarily opaline silica and calcium carbonate. The strontium and lead isotope ratios, which are sensitive to alteration, are similar in both altered and unaltered samples. This is an indication that no elemental mobilization was introduced during this alteration.

Activity 8.3.1.9.2.1.2 - Geophysical/geological appraisal of the site relative to mineral resources. The objective of this activity is to qualitatively evaluate the available geophysical data base as it relates to Study Plan 8.3.1.9.2.1. Geologic models derived from geophysical data will be evaluated for their impact on mineral resources.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.9.2.1.3 - Assessment of the potential for geothermal energy at Yucca Mountain, Nevada. The objective of this activity is to evaluate regional ambient heat flow and local heat flow anomalies. This activity assesses the geothermal regime in terms of its energy resource potential for either hydrothermal or conductive reservoir thermal systems.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.9.2.1.4 - Assessment of hydrocarbon resources at and near the site. The objectives of this activity are to determine the potential for the presence or absence of suitable source rocks, reservoir rocks, and traps and seals at or near the site; to determine the potential for occurrence of conventional hydrocarbon resources (crude oil and natural gas) at and near the site; and to provide necessary data for the overall mineral and energy resource assessment to be performed.

A paper by Grow et al. (1994) reports on new conodont color-alteration indices, total organic contents, and hydrogen indices obtained from Paleozoic rock samples obtained from exploration drillholes located in the region of Yucca Mountain. This new information is then considered in assessing the oil and gas potential in the region of Yucca Mountain. The oil and gas potential in the area of Yucca Mountain is low.

Activity 8.3.1.9.2.1.5 - Mineral and energy assessment of the site, comparison to known mineralized areas, and the potential for undiscovered resources and future exploration. The objective of this activity is to integrate the data and information collected from the geochemical assessment, geophysical/geologic assessment, geothermal energy assessment, and hydrocarbon assessment. Integration of these activities and the data acquired from them will allow the identification of mineral resources with current markets, as well as the calculation of gross and net values for identified resources or reserves; the physical description of mineral resources with potential future markets relative to "tonnage, or other amount, grade, and quality," as described in 10 CFR 60.21(c)(13); the physical description of energy resources using appropriate parameters that describe the extent and magnitude of those resources; the evaluation of the resource potential of any identified or undiscovered mineral and energy resources, based on a "representative" area of "similar size" and a comparison to the Yucca Mountain site as prescribed in 10 CFR 60.122(c)(17); and an estimation of the potential for undiscovered deposits of those resources described in 10 CFR 60.21(c)(13).

No progress during the reporting period; this was an unfunded activity.

Forecast: The USGS will submit to the Yucca Mountain Technical Data Base previously collected downhole temperature data and geochemical data including sample locations, sample descriptions, and elemental abundance data. These data will then be available for the assessment of natural resources within the controlled area of Yucca Mountain.

Additional geochemical and resource assessment work is being considered. No revision to the current study plan is expected. The work would include a new sampling initiative for both surface and subsurface sampling and would employ multiple analytical techniques. Appropriate levels of analytical detection will be the main focus of the analytical techniques selected. The assessment work is intended to be carried out by a participant with strong technical expertise in the assessment of natural resources. The work may begin in FY 1995.

3.7.3 Study 8.3.1.9.2.2 - Water Resource Assessment of Yucca Mountain, Nevada

The objective of this study is to use available data to estimate the future supply, demand, and value of the ground-water resource in southern Nevada, proximal to Yucca Mountain.

No progress during the reporting period; this was an unfunded study.

Activity 8.3.1.9.2.2.1 - Projected trends in local and regional ground-water development and estimated withdrawal rates in southern Nevada, proximal to Yucca Mountain. The objectives of this activity are to assess the current and projected supply and demand situation for ground water in the geohydrologic study and to estimate the value of the ground-water resource.

Forecast: No activity is planned for FY 1995.

3.7.4 Study 8.3.1.9.3.1 - Evaluation of Data Needed to Support an Assessment of the Likelihood of Future Inadvertent Human Intrusion at Yucca Mountain as a Result of Exploration and/or Extraction of Natural Resources

The objective of this study is to compile and analyze data to assess the likelihood of inadvertent human interference in the Yucca Mountain vicinity.

No unique data are to be acquired by this study. The results of Study 8.3.1.9.2.1 will be a major, direct input to this study. Other inputs will be acquired from existing study plans or available data.

Activity 8.3.1.9.3.1.1 - Compilation of data to support the assessment calculation of the potential for inadvertent human intrusion at Yucca Mountain. The objectives of this activity are to determine the maximum drilling density and frequency (drillholes per square kilometer per 10,000 years) that can be reasonably assumed for a repository at Yucca Mountain; and to determine the extent to which future ground-water withdrawals will modify the expected ground-water flow paths.

Forecast: There will be no study plan developed for this Site Characterization Plan section. A DOE working paper will be developed to document and discuss input parameters for inadvertent intrusion performance modeling using direct inputs from Study 8.3.1.9.2.1 and other studies.

3.7.5 Study 8.3.1.9.3.2 - An Evaluation of the Potential Effects of Exploration for, or Extraction of, Natural Resources on the Hydrologic Characteristics at Yucca Mountain

The objective of this study is to assess, in qualitative or quantitative terms, the effects of exploiting natural resources known or believed to be present at Yucca Mountain. Consideration of the effects of resource exploitation or extraction are limited to changes in the hydrologic, geochemical, and rock characteristics.

No unique data are to be acquired by this study. The inputs to computer modeling for varying water withdrawal assumptions and input bounds for sensitivity analysis of the code will be supplied directly from Study Plan 8.3.1.9.2.2. The use of expert judgment such as is identified in Activity 2, should it be employed, will be subject to a controlled and documented management process to be described in a planning document other than a study plan.

Forecast: There will be no study plan developed for this Site Characterization Plan section.

3.8 METEOROLOGY (SCP SECTION 8.3.1.12)

3.8.1 Study 8.3.1.12.1.1 - Characterization of the Regional Meteorological Conditions

The objective of this study is to gather and analyze meteorological data from various locations to characterize the regional meteorology and assimilate that information into a regional summary report. This characterization will provide a regional overview of wind flow patterns and other meteorological parameters (related to atmospheric dispersion) associated with those patterns in and around Yucca Mountain.

Three Site Characterization Plan studies and one investigation in the Meteorology Program (8.3.1.12) include work to describe current regional meteorological conditions: Study 8.3.1.12.1.1, "Characterization of the Regional Meteorological Conditions," Study 8.3.1.12.1.2, "Plan for Synthesis of Yucca Mountain Site Characterization Project Meteorological Monitoring," Investigation 8.3.1.12.3, "Studies to Provide Data on the Location of Population Centers Relative to Wind Patterns in the General Region of the Site," and Study 8.3.1.12.4.1, "Characterize the Potential Extreme Weather Phenomena and their Recurrence Intervals." These studies (and the investigation) were identified as suitable for control through other means than study plans. The planning documentation for this work is being written as a Scientific Investigation Implementation Package by the M&O. The Scientific Investigation Implementation Package will serve as the management plan to report the results of analyses, syntheses, and compilation exercises described in Site Characterization Plan Section 8.3.1.12.1.2. The plan will serve to integrate the work to be completed under the remainder of Section 8.3.1.12.

A meeting of the primary groups in YMP that collect and use meteorological data was held in July 1994. The work planned for this Scientific Investigation Implementation Package was discussed to ensure that interfaces between data collection groups could continue, and that groups requiring information can expect to obtain it in a timely fashion.

Forecast: There will be no further study plans developed for this Site Characterization Plan program. Work to complete the Scientific Investigation Implementation Package is in progress. The document should be completed during the next reporting period.

3.8.2 Study 8.3.1.12.1.2 - Plan for Synthesis of Yucca Mountain Site Characterization Project Meteorological Monitoring

The objective of this study is to develop a plan that provides for coordination of meteorological monitoring efforts prepared during site characterization by various YMP participants.

The work in this study is intended to be combined with other studies into a Scientific Investigation Implementation Package. See Section 3.8.1 of this Progress Report.

3.8.3 Study 8.3.1.12.2.1 - Meteorological Data Collection at the Yucca Mountain Site

The objective of this study is to provide data to resolve design and performance issues associated with preclosure radiological safety.

Activity 8.3.1.12.2.1.1 - Site meteorological monitoring program. The objective of this activity is to collect meteorological data at potential locations of surface facilities and at a sufficient number of additional locations deemed necessary to characterize the wind flow patterns in the vicinity of Yucca Mountain.

The ongoing meteorological monitoring program continued at the nine active sites. This program is currently focused on data collection. The information is intended for future site suitability and licensing work in estimating potential radiological dosage related to repository operations.

Data from the network were included in the next two quarterly ambient air monitoring reports submitted to the State of Nevada during this reporting period. These reports fulfill requirements for the State Air Quality Permit No. AP9999-0076, which covers site characterization surface disturbing activities. No significant increase in inhalable particulate matter (PM_{10}) concentration has been noted during the increase in surface disturbing activities. Data requests from other project participants are being completed in a timely manner.

Activity 8.3.1.12.2.1.2 - Data summary for input to dose assessments. The objective of this activity is to process the collected meteorological data into a format and content that will be useful in assessing radiological impacts, as required by design and performance issues.

No progress during the reporting period; this was an out-year activity. Work cannot proceed effectively on this topic until the type of atmospheric dispersion model is chosen.

Forecast: Data collection will continue at the nine sites during FY 1995.

3.8.4 Study 8.3.1.12.3 - Studies to Provide Data on the Location of Population Centers Relative to Wind Patterns in the General Region of the Site

The objective of this study is to provide data on wind flow patterns in the general region of Yucca Mountain. These data will then be used in estimating doses to the public and in doing so ensure that wind flow patterns would not preferentially transport material towards population centers.

The work in this study is intended to be combined with other studies in a new Scientific Investigation Implementation Package. See Section 3.8.1 of this Progress Report.

A draft report was submitted for review on the special intensive field study program performed during late autumn 1993 with participation from the National Oceanic and Atmospheric Administration's Atmospheric Turbulence and Diffusion Division from Oak

Ridge Tennessee, and the National Weather Service's Nuclear Support Office from Las Vegas and Mercury, Nevada. The study purpose was to characterize nighttime downslope airflow related to the west and east sides of the main Yucca Mountain ridge. These conditions may be the "worst-case" atmospheric dispersion related to possible releases of airborne radioactive material in terms of impacts to the public. Preliminary results of this field study indicate that additional measurements should be taken in the Crater Flat area to better characterize the airflow on the west side of Yucca Mountain.

Forecast: The report from the study will be completed during FY 1995.

3.8.5 Study 8.3.1.12.4.1 - Characterize the Potential Extreme Weather Phenomena and Their Recurrence Intervals

The objective of this study is to evaluate existing historical meteorological and climatological records, technical publications, and other relevant information to quantify the extreme weather phenomena that may be expected at the Yucca Mountain site and determine their recurrence interval.

The work in this study is intended to be combined with other studies in a Scientific Investigation Implementation Package. See Section 3.8.1 of this Progress Report.

3.9 OFFSITE INSTALLATIONS AND OPERATIONS (SCP SECTION 8.3.1.13)

The radiological environmental monitoring program has been designed to provide, among other things, the data necessary to fulfill the objectives of Site Characterization Plan Section 8.3.1.13. Data from this program will form the basis of all future radiological monitoring programs and will be used to identify any possible future radiological impacts on the environs of Yucca Mountain.

The data generated by this program are reported for each calendar year. Soil and air samples are collected and analyzed for radionuclide concentrations. Ambient gamma exposure and environmental radon concentrations are also measured. The process of validating data continued during the reporting period. Collection and analysis of small mammal and vegetation samples has been suspended.

Data from the previous calendar year was presented in the "Site Environmental Report for Calendar Year 1993" (DOE, 1994x) and in the fifth "Environmental Monitoring and Mitigation Plan Progress Report" (DOE, in prep.[e]) currently undergoing DOE review.

Forecast: Collection of soil and airborne particulates will continue through FY 1995, as will measurements of ambient gamma exposure rates and environmental radon concentrations. The collection of vegetation samples, suspended in FY 1994, is scheduled to resume in FY 1995. Data validation of backlog data will continue through FY 1995.

3.10 SURFACE CHARACTERISTICS (SCP SECTION 8.3.1.14)

3.10.1 Study 8.3.1.14.2.1 - Exploration Program

The objective of this study is to conduct an exploration program for characterization of the soil and rock conditions that will influence or be influenced by the construction of the surface facilities and the subsurface access ramps and shafts. The exploration program study will consist of site reconnaissance, and preliminary and detailed exploration.

Activity 8.3.1.14.2.1.1 - Site reconnaissance. The objective of this activity is to review existing site information and conduct a field reconnaissance to establish a preliminary exploration program to include further topographic and geologic mapping, subsurface drilling, test pits, trenching, and geophysical methods.

Activity 8.3.1.14.2.1.2 - Preliminary and detailed exploration. The objective of this activity is to obtain sufficient surface and subsurface data to prepare a preliminary design for the Exploratory Studies Facility surface and subsurface access facilities. Preliminary designs based on these explorations will be suitable for economic and technical feasibility reports and YMP planning reports.

Exile Hill investigations of the nonlithified Rainier Mesa Tuffs were completed and several Technical Data Information Forms were submitted in support of Exploratory Studies Facility design

Forecast: Cross sections will be developed for the main drift, and a geoengineering report on rock properties for the main drift will be developed for review.

3.10.2 Study 8.3.1.14.2.2 - Laboratory Tests and Material Property Measurements

The objective of this study is to conduct laboratory tests and material property measurements on representative samples of soil and rock. These tests and measurements are intended to determine physical, mechanical, and dynamic properties. Additional tests and measurements will be conducted on soils to determine index properties and moisture-density compaction curves for potential fill material.

Activity 8.3.1.14.2.2.1 - Physical property and index laboratory tests. The objective of this activity is to measure the soil or rock weight and volume components using physical property tests.

Activity 8.3.1.14.2.2.2 - Mechanical and dynamic laboratory property tests. The objective of this activity is to measure in the laboratory the static and dynamic deformation and strength characteristics of soil and rock samples obtained from the exploratory program. The results of this testing will be used to evaluate bearing capacity, earth pressures, shear strength parameters, slope stability, settlement and swelling potentials, and the dynamic characteristics of the soil and rock.

Laboratory tests were completed on samples from the Rainier Mesa nonlithified tuffs from UE-25 NRG#26 and Trench NRT-1. Moisture content, gradation, bulk density, and specific gravity tests were performed. The results of these tests are reported by Kessel et al. (in prep.).

The results of thermal and mechanical properties tests to support Exploratory Studies Facility design are reported in Sections 3.11.1 through 3.11.4.

Forecast: Laboratory tests will be conducted on representative samples of soil and rock to provide geotechnical data to support the design group for the design of the Exploratory Studies Facility and surface facilities. Testing supports the development of rock quality estimates and rock mass mechanical properties for tunnel support design and design of foundations for muck conveyor systems.

3.10.3 Study 8.3.1.14.2.3 - Field Tests and Characterization Measurements

The objective of this study is to conduct field tests and characterization measurements. These field tests are intended to determine the in situ physical, mechanical, and dynamic properties of the soil and rock.

Field tests were conducted in Trench NRT-1. The tests included sandcone density, nuclear density, plate load, standard penetration tests, permeability and a stand-up time demonstration test. Auger holes UE-25 NRG #2c and NRG 2d were drilled and standard penetration tests were performed in these holes. Lithologic logs for these hole were developed. Trench NRT-1 was mapped and a cross correlation of individual units within the pre-Rainier Mesa Bedded Tuffs, including paleosol intervals at the top of each unit between Boreholes UE-25 NRG#2, #2a, #2b,#2c, #2d and Trench NRT-1 were developed. The results of the geologic logging, mapping and field tests are reported by Kessel et al. (in prep.).

Activity 8.3.1.14.2.3.1 - Physical property field tests and characterization measurements. The objectives of this activity are to classify and describe the soil and rock conditions in the field and to determine their physical properties. The results of these tests and measurements will be used to develop estimates of the engineering characteristics of the soil and rock. In addition, these properties and measurements will aid in the grouping of soil and rock into stratigraphic units and the extrapolation of results from a restricted number of mechanical and dynamic properties tests to zones of soil and rock with similar material properties.

Activity 8.3.1.14.2.3.2 - Mechanical property field tests. The objective of this activity is to measure the deformation and strength characteristics of in situ soil and rock conditions. The results of this testing will be used to evaluate bearing capacity, earth pressures, settlement and swelling potentials, slope stability, and the dynamic response of soil and rock for the design of foundations, retaining walls, backfills, roads, slopes, ramps, and shafts.

Activity 8.3.1.14.2.3.3 - Geophysical field measurements. The objectives of this activity are to obtain measurements of the compressional and shear wave velocities and to determine the velocity structure in the area of the Exploratory Studies Facility surface facilities and subsurface ramps and shafts. These methods may also be used to profile the alluvium-bedrock contact, locate discontinuities or other structural abnormalities, and to determine the depth, thickness, and lateral extent of soil and rock stratigraphic units.

Forecast: Structural and geologic logs will be prepared for USW SD-12, SD-9, and SD-7. Soils engineering field tests will be conducted to support design of the Exploratory Studies Facility North Portal water storage system and the muck conveyor system.

3.11 THERMAL AND MECHANICAL ROCK PROPERTIES (SCP SECTION 8.3.1.15)

3.11.1 Study 8.3.1.15.1.1 - Laboratory Thermal Properties

The objective of this study is to provide laboratory characterization of thermal conductivity and heat capacity and the spatial variability thereof. To accomplish this, porosity, grain density, and the heat capacity and thermal conductivity of zero-porosity material must also be characterized.

Preliminary results of mineralogic, petrologic, and whole rock chemistry of samples from Fran Ridge TSw2 used in the Bench Scale Backfill Test indicate that, if these samples are characteristic of the south end of Yucca Mountain, the widespread distribution of cristobalite throughout the nonporous matrix could affect the thermomechanical behavior of the rock to a greater extent than was observed from test specimens in the north end of the repository block.

Activity 8.3.1.15.1.1.1 - Density and porosity characterization. The objective of this activity is to obtain data on density and porosity and to evaluate the spatial variability thereof. Data will contribute to determination of in situ thermal properties (porosity and grain density), to vertical in situ stress (bulk density), and radiation-shielding properties (bulk density).

Bulk properties, grain densities, mineralogical, petrologic, and bulk chemical characterization are being obtained to aid in the interpretation of thermal properties and thermal expansion test results. These data are required to examine potential correlation between thermal properties and sample characteristics and to develop predictive models for thermal properties.

Activity 8.3.1.15.1.1.2 - Volumetric heat capacity characterization. The objective of this activity is to obtain data for volumetric heat capacity and to evaluate the spatial variability thereof. The data will be used in calculations of the thermal response to the presence of heat-producing waste in unit TSw2.

Equipment and procedures to conduct heat capacity measurements were developed.

Activity 8.3.1.15.1.1.3 - Thermal conductivity characterization. The objective of this activity is to obtain data for thermal conductivity and to evaluate the spatial variability thereof. The data will be used in calculations of the thermal response to the presence of heat-producing waste in unit TSw2.

Thermal conductivity is a fundamental material property needed for all heat transfer calculations. Testing for the effects of saturation on thermal conductivity was completed. The data show that, for a given saturation, thermal conductivity does not change significantly with temperature. However, thermal conductivity does change significantly with saturation level and porosity. Results of thermal conductivity testing on samples from USW NRG-6 were submitted to the SNL participant data archive and are now available for use by all participants.

Forecast: Tests will continue in the characterization of samples from Boreholes USW NRG-7, SD-7, SD-9, and SD-12. By conducting sample characterization, differences in thermal properties among rocks in the same thermomechanical unit can be explained. Additionally, thermal properties can be tied to other site characterization data. Both of these uses will ultimately reduce the number of thermal tests that will be needed. A suite of characteristics will be measured and recorded. Heat capacity and thermal conductivity measurements will be made on samples from the boreholes mentioned above. The calculations support Exploratory Studies Facility and repository designers and performance assessment calculations. Reports discussing the data and its significance will be prepared in FY 1995.

3.11.2 Study 8.3.1.15.1.2 - Laboratory Thermal Expansion Testing

The objective of this study is to provide laboratory characterization of thermal-expansion behavior and the spatial variability thereof. Testing frequency at the Main Test Level in the Exploratory Studies Facility will depend on spatial variability.

In order to determine the optimum sample sizes and saturation states for laboratory thermal expansion tests, studies were conducted to determine whether (1) measured thermal expansion has a predictable dependence on the sample size for different lithologies of tuff, and (2) thermal expansion has a predictable dependence on the saturation state of the sample.

Activity 8.3.1.15.1.2.1 - Thermal expansion characterization. The objective of this activity is to obtain data for thermal-expansion behavior and to evaluate the spatial variability thereof. The data will be used in calculations of thermal stress and deformation associated with the temperature field produced by the presence of heat-producing waste in unit TSw2.

The coefficient of thermal expansion is a fundamental material property that is needed for calculations involving thermal expansion. These data support Exploratory Studies Facility and repository design and are used to calculate the induced thermal stress that will result from waste emplacement. Knowledge of the induced thermal stress is required to design stable underground openings. Testing to determine the effects of sample size on thermal expansion

testing was completed in June 1994. An interim data transmittal was submitted to the SNL Participant Data Archive in July 1994.

Preliminary results of the thermal expansion tests conducted on samples from USW NRG-6 were completed and an interim data transmittal was submitted to the SNL Participant Data Archive.

Forecast: Thermal expansion measurements will be made on samples from boreholes USW NRG-7a, SD-7, SD-9, and SD-12. Effects of confinement of thermal expansion will also be investigated. Reports summarizing thermal expansion data will be produced in FY 1995.

3.11.3 Study 8.3.1.15.1.3 - Laboratory Determination of Mechanical Properties of Intact Rock

The objective of this study is to provide laboratory characterization of the mechanical properties of intact rock and the spatial variability thereof. Testing frequency at the Main Test Level in the Exploratory Studies Facility will depend on spatial variability.

Activity 8.3.1.15.1.3.1 - Compressive mechanical properties of intact rock at baseline experiment conditions. The objective of this activity is to obtain data for the comprehensive mechanical properties of intact rock and the spatial variability thereof for baseline experiment conditions. These data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Samples have been collected for intact mechanical properties testing. During this reporting period, samples from USW NRG-7/7a were prepared and tested. The samples are characterized and prepared, and then three types of experiments are performed: unconfined compression, confined compression, and indirect tension (Brazil). The results from a total of 16 unconfined compression, 23 confined compression, and 53 Brazil experiments have been sent to the SNL Participant Data Archive. In addition, average grain density was determined and reported for 83 samples. The results from these experiments have been analyzed relative to the stratigraphic position within the hole, to equivalent stratigraphic positions in other holes that have been tested, and to characteristic bulk properties. The addition of this data to the data base from previously tested holes has refined and strengthened the relationships among many of the mechanical properties and porosity (Price et al., in prep.). However, the only data that have been collected are on samples from the NRG series of drillholes, and additional data is required from the SRG and SD series of holes before a comprehensive conclusion may be made about the relationships.

Testing of several rock types has been conducted at eight government and private rock mechanics laboratories in support of the American Society for Testing and Materials/Institute for Standards Research Steering Committee for the Interlaboratory Testing Program for Rock Properties. Test data supporting the committee's Phase II testing program have been

submittd as a draft report, which will eventually be an American Society for Testing and Materia/Institute for Standards Research report. The report suggests measures of precision for pubshed rock-property standards (Pincus, in prep.).

Activity 8.3.1.15.1.3.2 - Effects of variable environmental conditions on mechanical properties. The objective of this activity is to evaluate the effects of varying sample size, strain rae, temperature, confining pressure, lithophysal content, saturation state, and anisotroy on compressive mechanical properties. In addition, the tensile strength of unit TSw2 will be measured. Data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and ovelying units and by the presence of heat-producing waste in unit TSw2.

A study of time-dependent deformation involving high-temperature experiments at creep and low strain rate conditions was conducted. The most recent series of experiments consist of samples of TSw2 to be tested at a pore pressure of 4.5 MPa, a confining pressure of 5 MPa, and a maximum constant differential stress of 80 MPA. Initially, the experiments are performed with a series of stress steps at room temperature, which is then repeated at 250°C. In the last six months, two long-term experiments were completed. The results supported earlier findings that very little primary or secondary creep is exhibited by these welded tuffs under these repository-type conditions.

Forecast: Experiments will continue on samples from NRG and SD drillhole core. The data will be reduced, analyzed, and reported in support of Exploratory Studies Facility design activities and site characterization. Creep experiments to investigate time-dependent mechanical properties and triaxial compression tests of elevated temperature and pressure will also continue, as will minimal support of the American Society for Testing and Materials/Institute for Standards Research Steering Committee.

3.11.4 Study 8.3.1.15.1.4 - Laboratory Determination of the Mechanical Properties of Fractures

The objective of this study is to provide laboratory characterization of the mechanical properties of fractures and the spatial variability thereof. The discussion applies for each new core hole and for the Exploratory Studies Facility.

The Fracture Properties Working Group met six times during the reporting period, with the discusions centering on revising the study plan and testing activities supporting Exploratory Studies Facility design efforts.

Activity 8.3.1.15.1.4.1 - Mechanical properties of fractures at baseline experiment condition. The objective of this activity is to obtain data for the mechanical properties of fractures, and the spatial variability thereof, for baseline experiment conditions. The data will be used in mechanical and thermomechanical calculations of the stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Rotary friction (axial compression-torsion) has been chosen as the test technique for gathering the majority of the data on the mechanical properties of natural fractures gathered from core taken in the NRG series of drillholes.

In the last six months, twelve natural fractures from UE 25 NRG-4 and USW NRG-6 were characterized by gathering topographic information on each sample with a laser profilometer, and testing began. The results have shown a surprising lack of a distinct peak shear stress, which is normally associated with interlocked fractures. These samples have, in general, had a rounded peak shear response with a slow decrease in the shear strength to a residual, sliding value.

Activity 8.3.1.15.1.4.2 - Effects of variable environmental conditions on mechanical properties of fractures. The objective of this activity is to evaluate the effects of varying normal stress, displacement rate, temperature, sample size, fracture roughness, and saturation state on the mechanical properties of artificial and natural fractures. The data will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

Development continued of a computer program to model the dilation, normal stiffness, and shear stiffness of single fractures in rock. An early version of the code is being used to study the changes in the aperture of a fracture under normal stress.

Forecast: Experiments will continue on samples from NRG and SD drillhole core. Some tests will be conducted at elevated temperatures. The data will be reduced, analyzed, and reported in support of Exploratory Studies Facility design activities.

3.11.5 Study 8.3.1.15.1.5 - Excavation Investigations

The objective of this study is to obtain site-specific information concerning the behavior of underground excavations in the proposed repository horizon and overlying units. Most of the data will be used for testing of computer codes that will be used to predict mechanical behavior of the rock mass. In addition, some of the information will serve as direct demonstration of constructability with reasonably available technology.

The study plan was revised to incorporate changes required by the new Exploratory Studies Facility design. On March 4, 1994, all the responses to comments on the revised study plan were accepted. The excavation investigations experiments are designed to demonstrate constructability and long-term stability of full-scale underground openings and provide data for assessing the validity of the rock mass constitutive models that will be used to design the repository and support the License Application.

Activity 8.3.1.15.1.5.1 - Access convergence experiment. The objective of this activity is to monitor rock-mass deformation around a vertical shaft and to measure horizontal in situ stresses. In situ stress data will contribute to definition of boundary and initial conditions for

mechanical and thermomechanical analyses, whereas observations of rock-mass deformation will also contribute to empirical evaluations of nonradiological health and safety.

The first of three excavation investigations experiments, the access convergence experiment, can be implemented in the North Ramp of the Exploratory Studies Facility as it is excavated by the tunnel boring machine. By measuring the displacement of the gripper pads on the tunnel boring machine, rock-mass compliance information can be obtained for use in repository and Exploratory Studies Facility design. In order to ensure that quality data can be obtained in a consistent and rigorous manner, planning documents were developed as prescribed by Quality Assurance and environmental, safety, and health requirements.

Activity 8.3.1.15.1.5.2 - Demonstration breakout room. The objective of this activity is to demonstrate constructability and stability of underground rooms with cross-sectional dimensions equivalent to those of a repository in both lithophysae-rich and lithophysae-poor material. This demonstration will include an evaluation of the deformations that occur around the openings. A secondary objective is to provide facilities for other testing (e.g., heater tests and overcoring). Demonstration of constructability and stability will contribute to empirical evaluations of nonradiological health and safety.

Activity 8.3.1.15.1.5.3 - Sequential drift mining. The objectives of this activity are to obtain data on the deformation response of drifts with cross-sectional dimensions equivalent to those of a repository in welded tuff, to use the data in code evaluation activities, and to demonstrate constructability and stability of repository-sized drifts in lithophysae-poor material. Data will contribute to validation of computer codes to be used to calculate mechanical responses, as well as contributing to empirical evaluations related to nonradiological health and safety.

No progress during the reporting period; these were out-year activities.

Forecast: An investigation will be conducted to determine the feasibility of using the tunnel boring machine gripper pads to measure the compliance of the rock mass. Rock mass is a fundamental mechanical property used by designers.

3.11.6 Study 8.3.1.15.1.6 - In Situ Thermomechanical Properties

The objective of this study is to obtain data on in situ thermal and thermomechanical properties for units TSw1 and TSw2. Properties to be obtained include heat capacity, thermal conductivity, and thermal expansion. Additional heater experiments will be conducted to characterize the waste container environment.

The study plan for in situ thermomechanical properties was prepared.

Analyses were conducted (Holland and Pott, in prep.) to determine the temperature, displacement and stress fields that will result from the in situ thermomechanical experiments.

These analyses are needed to determine test separation distances and to facilitate the planning of the experiments.

Activity 8.3.1.15.1.6.1 - Heater experiment in unit TSw1. The objective of this activity is to estimate the in situ thermomechanical properties of lithophysae-rich tuff (unit TSw1) and to evaluate the thermal and mechanical response of this tuff unit to elevated temperatures. The data will be used to evaluate models during this and other experiments.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.15.1.6.2 - Canister-scale heater experiment. The objective of this activity is to obtain thermal and thermomechanical rock-mass measurements of the effects of thermal inputs on a representative (canister-scale) waste-emplacement borehole in lithophysae-poor tuff (unit TSw2). The data will be used to evaluate the thermal and thermomechanical models.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.15.1.6.3 - Yucca Mountain heated block. The objective of this activity is to estimate in situ mechanical and thermomechanical properties of unit TSw2 and to test thermomechanical computer models. Data on the properties will be used in mechanical and thermomechanical calculations of stresses and deformations induced by the presence of underground openings in unit TSw2 and overlying units and by the presence of heat-producing waste in unit TSw2.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.15.1.6.4 - Thermal stress measurements. The objective of this activity is to monitor thermally induced stress in jointed welded tuffs in an accelerated test. The data will be used to evaluate thermally induced stresses calculated with thermomechanical computer codes.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.15.1.6.5 - Heated room experiment. The objectives of this activity are to evaluate the thermomechanical response of welded tuff around repository openings to expected repository conditions during both construction and operation; to develop a data base for evaluating thermal and thermomechanical design analyses and methods applicable for repository considerations; and to use actual site data in predicting drift response and support/rock interactions during construction, operation, retrievability, and postclosure.

No progress during the reporting period; this was an out-year activity.

Forecast: The final study plan, incorporating responses to the comments received from internal review, will be submitted to YMSCO by August 30, 1995. In parallel, design reports for thermal tests to be conducted in the North Ramp Extension will be defined. Exploratory

Studies Facility designers need the test specifications in order to design the test drifts and procure the necessary excavation equipment to construct the test drifts.

3.11.7 Study 8.3.1.15.1.7 - In Situ Mechanical Properties

The objective of this study is to obtain in situ measurements of the mechanical properties of the rock mass for unit TSw2.

A draft of the study plan was completed.

Activity 8.3.1.15.1.7.1 - Plate loading tests. The objective of this activity is to measure the deformation modulus of the rock mass and to evaluate the zone of increased fracturing adjacent to underground openings.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.15.1.7.2 - Rock-mass strength experiment. The object of this activity is to evaluate the mechanical behavior of the rock mass or its components by using experiments to obtain information related to the mechanical strength of single joints and to multiply jointed volumes of rock.

No progress during the reporting period; this was an unfunded activity.

Forecast: The final study plan will be revised (incorporating changes that result from programmatic re-direction) and submitted to YMSCO by the end of FY 1995. In parallel, in situ mechanical properties experiments to be conducted will be designed, hardware identified, and test procedures developed. Exploratory Studies Facility designers need the test specifications to design the test drifts and procure the necessary excavation equipment to construct the test drifts.

3.11.8 Study 8.3.1.15.1.8 - In Situ Design Verification

The objectives of this study are to investigate the effects of the spatial variability of the rock on drift stability, mining activities, and ground supports; to evaluate techniques for underground excavation and ground support, for selecting ground supports to be used in different rock types, and for monitoring drift stability; to quantify the emanation of radon into repository drifts and observe its dispersion with airflow; and to measure parameters needed to design repository ventilation systems.

The objective of the geotechnical design validation activities being conducted in the North Ramp Starter Tunnel is to confirm adequate design, construction, and long-term performance of the underground openings from the inception of construction. Data measured in the experiments are being used to further the design of the Exploratory Studies Facility and to develop design methods for the repository. A summary of the design validation activities

conducted to date at Yucca Mountain was presented at the North American Tunneling Conference on June 7, 1994, in Denver, Colorado (Pott et al., 1994) To ensure that quality data can be obtained in a consistent and rigorous manner, planning documents for fielding the in situ design validation activities in the Exploratory Studies Facility North Ramp were developed as prescribed by Quality Assurance and environmental, safety, and health requirements.

Activity 8.3.1.15.1.8.1 - Evaluation of mining methods. The objective of this activity is to develop recommendation for mining in the repository by monitoring and evaluating mining activities in the Exploratory Studies Facility and by conducting mining investigations.

Peak particle velocities resulting from construction blasting of the North Ramp Starter Tunnel and its alcove were measured. These data and subsequent analyses will be used in future construction blasting to design blast rounds that will minimize damage to the surrounding rock.

Activity 8.3.1.15.1.8.2 - Monitoring of ground-support systems. The objective of this activity is to develop recommendations for a ground-support methodology to be used in drifts in the repository, based on evaluations of the ground-support methodology used in the Exploratory Studies Facility and on experimentation with other ground-support configurations. Recommendations will be made for support systems to be used, as well as for methods of selection of supports that are appropriate for the ground conditions encountered.

Load cells were installed and monitored on selected rock bolts in the North Ramp Starter Tunnel and its alcove. Data from these cells and subsequent analyses will be used to evaluate the sufficiency of the installed ground support.

Activity 8.3.1.15.1.8.3 - Monitoring drift stability. The objectives of this activity are to provide confidence in predictions of usability of the repository underground facilities over their 100-year operational life, to contribute to evaluations of the effectiveness of mining methods and ground supports, to calibrate and refine criteria for determining stability of the openings, and to develop techniques for monitoring stability of the repository drifts.

Cross-drift convergence pins and multipoint extensometers were installed at selected locations in the North Ramp Starter Tunnel and its alcove. Using these instruments, the movement of the walls of the underground openings was monitored. These data and subsequent analyses will be used to evaluate long term stability of the openings.

Activity 8.3.1.15.1.8.4 - Air quality and ventilation experiment. The objectives of this activity are to measure the rate of radon emanation from the repository host rock; and to evaluate parameters and variables needed as input to or for testing of the models to be used for design of the ventilation systems in the repository underground facility.

No progress during the reporting period; this was an unfunded activity.

Forecast: Mining methods employed in the North Ramp alcoves will be evaluated as to the extent of the damage zone resulting from construction in the rock surrounding the alcoves. Measurements will be taken of far-field peak particle velocities, near-field peak particle velocities, and in situ stress as a function of distance from alcove walls. Instruments will be installed in the North Ramp and regular readings recorded to measure the performance of the ground support system and to determine the stability of the ramp. These data are needed by the Exploratory Studies Facility designers to allow them to make design validation calculations and to assist them in their safety evaluations. A report on the data from the North Ramp Starter Tunnel will be provided in FY 1995.

3.11.9 Study 8.3.1.15.2.1 - Characterization of the Site Ambient Stress Conditions

The objective of this study is to characterize the ambient (pre-repository) state of stress of the Yucca Mountain host rock and surrounding units for use as initial conditions for geomechanical models used in the design and performance assessment of the repository underground facilities.

Activity 8.3.1.15.2.1.1 - Anelastic strain recovery experiments in core holes. The objective of this activity is to determine the horizontal stresses at Yucca Mountain, particularly the spatial variability thereof. In situ stress data will contribute to definition of initial and boundary conditions for mechanical and thermomechanical analyses.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.15.2.1.2 - Overcore stress experiments in the Exploratory Studies Facility. The objectives of this activity are to determine the in situ state of stress above, within, and below the repository host rock in that portion of the repository block penetrated by the Exploratory Studies Facility; and to evaluate the extent to which the ambient stress conditions are redistributed adjacent to excavations. In situ stress data will contribute to definition of initial and boundary conditions for mechanical and thermomechanical analyses.

The scope of work for this activity has been transferred to Study 8.3.1.15.1.8.

Forecast: As a result of the study plan work scope consolidation, there will be no study plan developed for this Site Characterization Plan section. The work scope for Activity 8.3.1.15.2.1.1 is being deleted from the program. The proposed technique is not likely to work, would not be cost effective, and would be redundant with other planned approaches. The Site Design and Test Requirements Document will be revised to reflect these changes.

3.11.10 Study 8.3.1.15.2.2 - Characterization of the Site Ambient Thermal Conditions

The objective of this study is to evaluate available thermal data to determine the ambient (pre-repository) temperature and thermal conductivity of the Yucca Mountain host

rock and surrounding units for use as initial conditions for thermomechanical models used in the design and performance assessment of the repository underground facilities.

Activity 8.3.1.15.2.2.1 - Surface-based evaluation of ambient thermal conditions. The objective of this activity is to evaluate available thermal data to determine the ambient (pre-repository) temperature and thermal conductivity of the Yucca Mountain host rock and surrounding units for use as initial conditions for thermomechanical models used in the design and performance assessment of the repository underground facilities.

This activity was not funded in FY 1994. All work was carried out in the closely related Activity 8.3.1.8.5.2.3 heat flow at Yucca Mountain and evaluation of regional ambient heat flow and local heat flow anomalies.

Forecast: New temperature logs will be obtained from Borehole USW G-2 on the north end of the large hydraulic gradient. This work will be done in association with planned hydraulic testing of the borehole. These data will be used to evaluate if perched water occurs at this site and to characterize the directions and rates of intra-borehole flow. Both should yield information on the nature of the large hydraulic gradient. Temperature logs will be obtained in horizontal boreholes drilled across the Bow Ridge Fault from within the Exploratory Studies Facility. These logs may yield information about water and vapor movement within the fault in the unsaturated zone. Bulk rock samples from the Exploratory Studies Facility will be obtained at a later date to determine thermal conductivity to help interpret these logs. When a sufficient number of WT wells are reconfigured with heat-flow measurement access tubes, these wells will be logged and the results compared with previous logs. If the information is of sufficiently high quality, fluid movement may be detected in both the unsaturated and saturated zone.

3.12 PRECLOSURE HYDROLOGY (SCP SECTION 8.3.1.16)

3.12.1 Study 8.3.1.16.1.1 - Characterization of Flood Potential of the Yucca Mountain Site

The objective of this study is to evaluate the potential for flooding in the many small, dry, desert washes that drain Yucca Mountain. This evaluation will be used for designing the surface facilities for the proposed repository. Proper design for flood potential is necessary to ensure the safety of workers and surface facilities.

Activity 8.3.1.16.1.1.1 - Site flood and debris hazards studies. The objective of this activity is to assess the flood and debris hazards at and near the potential repository surface facilities locations to allow adequate design of facilities to prevent or reduce hazards to an acceptable level.

No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

3.12.2 Study 8.3.1.16.2.1 - Location of Adequate Water Supply for Construction, Operation, Closure, and Decommissioning of a Mined Geologic Disposal System at Yucca Mountain, Nevada

The purpose of this study is to identify water supply sources for a potential repository. Four activities were identified in the Site Characterization Plan: the first activity is to assess the cost, feasibility, and adequacy of using Wells UE-25 J#12 and J#13 as an alternative water supply; the second is to identify a primary water source; the third is to identify another alternative water source (other than Wells UE-25 J#12 and J#13); and the fourth is to identify and evaluate the potential effects of repository-related withdrawals on the ground water flow system.

Forecast: There will be no study plan developed for this Site Characterization Plan section. For the first activity, a DOE working paper or participant report will be developed compiling known production histories of UE-25 J#12 and J#13 from an extensive record. A second activity will identify a primary water supply for repository operations that is closer to, and topographically higher than, facilities important to safety; and a third activity will identify an alternative water source. This work concerns repository construction and is suited for a standard engineering trade study in support of a future design package for repository facilities important to safety. The fourth activity will provide for a sensitivity analysis with the flow models developed for Study 8.3.1.2.1.3, "Regional Ground Water Flow System," and Study 8.3.1.2.3.1, "Site Saturated Zone Ground Water Flow System." No activity is planned for FY 1995.

3.12.3 Study 8.3.1.16.3.1 - Determination of the Preclosure Hydrologic Conditions of the Unsaturated Zone at Yucca Mountain, Nevada

The objective of this study is to compile the data collected under Geohydrology Investigation 8.3.1.2.2, Exploratory Studies Facility Investigations, for input to Design Issue 4.4.

No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

3.13 PRECLOSURE TECTONICS (SCP SECTION 8.3.1.17)

3.13.1 Study 8.3.1.17.1.1 - Potential for Ash Fall at the Site

The objective of this study is to provide required information on volcanic activity that could affect repository design performance.

Activity 8.3.1.17.1.1.1 - Survey literature regarding Quaternary silicic volcanic centers in the western Great Basin. The objective of this activity is to compile information on

Quaternary silicic volcanism in the western Great Basin, the reoccurrence of which might produce an ash fall at the site.

Activity 8.3.1.17.1.1.2 - Assess potential ash-fall thickness at the site. The objective of this activity is to produce an approximate probability-vs.-thickness function for potential ash falls at the site and to estimate a particular ash-fall thickness that has less than one chance in ten of occurring in 100 years. These hazard estimates will be considered in the design of filters in the mining and surface-facility ventilation systems.

Forecast: As a result of the study plan work scope consolidation effort, there will be no study plan developed for this Site Characterization Plan section. All of these activities rely on data from other Site Characterization Plan studies, or available data. The work identified in this section has been completed and was documented in Perry and Crowe (1987). Additional discussion is included in the Los Alamos Volcanism Status Report.

Forecast: No progress during the reporting period; these were out-year activities.

3.13.2 Study 8.3.1.17.2.1 - Faulting Potential at the Repository

The objective of this study is to provide required information on fault displacement that could affect repository design or performance.

Activity 8.3.17.2.1.1 - Assess the potential for surface faulting at prospective sites of surface facilities important to safety. The objective of this activity is to assess the stability of the site surface with respect to fault displacement, at locations proposed for facilities important to safety.

Activity 8.3.17.2.1.2 - Assess the potential for displacement on faults that intersect underground facilities. The objective of this activity is to assess the potential for displacement on faults intersecting underground facilities.

Faulting potential at the site will be assessed in a manner similar to that used to assess vibratory ground motion. This probabilistic approach will allow the significance of faults with respect to design and performance assessment to be determined. Given the similarity in these approaches, the work scope for this study is being combined with that of Study 8.3.1.17.3.6 (Probabilistic Seismic Hazard Analysis). The study plan written for Study 8.3.1.17.3.6 during this reporting period addresses this assessment of faulting potential at and near Yucca Mountain.

Forecast: There will be no study plan developed for this Site Characterization Plan section. The work scope is to be transferred to Study Plan 8.3.1.17.3.6. The Site Design and Test Requirements Document will be revised to reflect this change.

3.13.3 Study 8.3.1.17.3.1 - Relevant Earthquake Sources

The objective of this study is to identify and characterize those earthquake sources relevant to seismic hazard analysis of the site (i.e., those sources that could cause significant surface fault displacement or ground shaking at the site).

During the current reporting period, the main outcome of this study was the preparation of Version IV of the Preliminary Table of Quaternary Fault and Seismic Source Parameters. This revision involved both identifying new earthquake sources for inclusion in the table and characterizing those sources based on available data. The table now summarizes interpretations of 88 potential fault sources and alternative configurations by providing fault type, potential rupture length, status of determination of Quaternary activity, maximum magnitude, surface displacements, fault slip rates, and recurrence intervals.

Activity 8.3.1.17.3.1.1 - Identify relevant earthquake sources. The objective of this activity is to identify earthquake sources that could generate significant surface fault displacements or severe ground motions at the site.

The Preliminary Table of Quaternary Fault and Seismic Source Parameters (Version IV), based on known and suspected Quaternary faults in the Yucca Mountain region, was updated and expanded. Emphasis was placed on including additional potential fault sources at regional distances. For some faults (e.g., Death Valley, Furnace Creek, Fish Lake Valley) alternative fault configurations were included by assuming adjacent fault segments could rupture in a single event. The viability of these alternative configurations will continue to be evaluated as additional data are collected in related field studies.

Fault parameters in the updated table were used along with attenuation relations to update the preliminary evaluation of which faults are capable of producing ground motions at Yucca Mountain of greater than 0.1 g peak acceleration. Potential site amplification effects are not included in this preliminary evaluation. Of the 88 faults or fault combinations listed in the table, 19 sources can produce median peak acceleration greater than 0.1 g. If acceleration values at the 84th percentile are considered, 35 faults can produce peak accelerations greater than the 0.1 g criterion. The results of this preliminary analysis were provided to Project scientists planning field studies of regional faults so that field work can be focused on the potentially more significant faults.

Activity 8.3.1.17.3.1.2 - Characterize relevant earthquake sources. The objective of this activity is to characterize each relevant earthquake source identified in the previous activity with a spatial description (including an expected depth or depth range), an assessment of activity, evaluations of maximum earthquake magnitude, the size and location of expected coseismic displacements (for sources in or near the controlled area), and the recurrence rate for earthquakes associated with the source. The source characterization includes an evaluation of variability in and dependency of input parameters.

Based on available information, Project scientists developed or updated preliminary evaluations for faults listed in the Preliminary Table of Quaternary Fault and Seismic Source

Parameters. The empirical relations of Wells and Coppersmith (in prep.) were used to determine maximum magnitudes and displacements for listed faults. Earthquake recurrence was characterized in terms of fault slip rate and the paleoseismic recurrent interval for late Quaternary surface-rupturing events.

Forecast: Existing and new data will continue to be analyzed to identify and characterize potential seismic sources. Paleoseismic, seismic, geologic, and geophysical data will be compiled and examined. Version V of the Preliminary Table of Quaternary Faults and Seismic Source Parameters will be available in FY 1995. Alternative attenuation relations will be considered in examining the potential relevance of Quaternary faults. The efforts of this study will be coordinated with those of Study 8.3.1.17.3.6 (Probabilistic Seismic Hazard Analysis) to make available to seismic source interpretation experts appropriate summaries of data and analyses.

3.13.4 Study 8.3.1.17.3.2 - Underground Nuclear Explosion Sources

The objective of this study is to characterize the potential future underground nuclear explosions at the Nevada Test Site that would result in the most severe motions at the repository site.

Activities 8.3.1.17.3.2.1 and 8.3.1.17.3.2.2. These activities rely on available data. No additional data are to be acquired.

Forecast: There will be no study plan developed for this Site Characterization Plan section. This work is substantially complete and the results will be reported in a participant Technical Report or a DOE Working Paper.

3.13.5 Study 8.3.1.17.3.3 - Ground Motion From Regional Earthquakes and Underground Nuclear Explosions

The objective of this study is to select or develop ground-motion models that are appropriate for estimating ground motion at the site from earthquakes and underground nuclear explosions. These models will be used to determine the relevancy of seismic sources to a deterministic seismic hazard analysis, identify controlling seismic events, constrain simulated ground motions from controlling seismic events, and estimate the probabilities of exceeding given ground-motion levels at the site.

During the current reporting period, progress was made in completing the two study plans that describe work to be carried out under the two activities associated with this study.

Activity 8.3.1.17.3.3.1 - Select or develop empirical models for earthquake ground motions. The objective of this activity is to select or develop empirical ground-motion models that are appropriate for estimating earthquake ground motion at the site. The models

will predict ground motion as a function of earthquake magnitude and distance between the earthquake source and the site.

The study plan was delivered to YMSCO during the first half of FY 1995. During the current reporting period, reviewer comments were received and are being addressed. Planning was carried out to implement the tasks described in the study plan in FY 1995, pending approval of the study plan.

Forecast: Once the study plan is approved, two tasks will be carried out in FY 1995. First, various ground motion modeling approaches will be examined with respect to their applicability at Yucca Mountain. Investigators will use different approaches to calculate deterministic ground motion at the surface facilities and at the depth of the potential repository for a number of earthquake scenarios. Conferences will be held to determine realistic earthquake scenarios that exercise the approaches over a range of magnitudes and distances and to calculate the resultant ground motion.

The second task will be to determine an empirical ground motion attenuation relation appropriate for Yucca Mountain. Seismograms from several normal-faulting earthquakes in the Great Basin will be used to establish empirical earthquake ground-motion-attenuation relationships of normal faults in the Yucca Mountain area. Source-station distances, earthquake moment magnitudes, and intensity of ground motion at each station will be used to determine variation of peak acceleration and various ground motion parameters (such as spectral velocity and acceleration).

Activity 8.3.1.17.3.3.2 - Select or develop empirical models for ground motion from underground nuclear explosions. The objective of this activity is to select or develop empirical ground-motion models that are appropriate for estimating ground motion at the site from underground nuclear explosions at the Nevada Test Site. The models will predict ground motion as a function of the yield and distance of the underground nuclear explosion.

The revised study plan was submitted to YMSCO in May 1994, incorporating YMSCO comments. During the current reporting period, comment resolution was completed and verified, and the approved study plan was transmitted to NRC. In preparation for carrying out the tasks described in the study plan, the assembly of ground motion data bases continued, and software QA activities were initiated.

Forecast: During FY 1995 three tasks will be accomplished. First, modeling of underground nuclear explosion data from Yucca Flat will be completed. Second, one-dimensional uphole/downhole modeling of underground nuclear explosion data will be carried out. Finally, the results of the first two tasks and previous work will be synthesized to provide an empirical model for ground motion at Yucca Mountain from underground nuclear explosions.

3.13.6 Study 8.3.1.17.3.4 - Effects of Local Site Geology on Surface and Subsurface Motions

The objective of this study is to document systematic effects on surface and subsurface ground motions resulting from the local site geology.

Activity 8.3.1.17.3.4.1 - Determine site effects from ground-motion recordings. The objective of this activity is to determine, from ground-motion recordings, the systematic effects of local site geology on surface and subsurface motions and to identify any significant site-wide bias in ground-motion levels, as compared with average levels for the Southern Great Basin.

The Midway Valley experiment was completed and the seismic data were analyzed to estimate site amplifications in the Midway Valley area. For this experiment, recordings from eight digital stations were combined with site amplification data from 12 Little Skull Mountain earthquakes. The geology of these sites also was mapped. For alluvium sites in Midway Valley, the data show very similar amplification effects at all sites (six stations). For bedrock sites (two stations), the recorded data were poor and therefore amplification determinations are characterized by large uncertainties. There was no obvious resonance in the frequencies (0.5 to 30 Hz) observed at these stations. Results of this study will be reported in an administrative report on seismic site effects in the vicinity of Yucca Mountain (Anderson and Su, in prep.).

Activity 8.3.1.17.3.4.2 - Model site effects using the wave properties of the local geology. The objective of this activity is to develop a calibrated theoretical site-effects model for use in extrapolating the observations documented in Activity 8.3.1.17.3.4.1 to locations and depths where ground-motion predictions are needed, but where instrumental recordings are not available.

Forecast: The site effects study is complete at the end of FY 1994.

3.13.7 Study 8.3.1.17.3.5 - Ground Motion at the Site From Controlling Seismic Events

The objective of this study is to identify the controlling seismic events and to characterize the resulting controlling ground motions. Controlling seismic events are those underground nuclear explosions or 10,000-year cumulative-slip earthquakes that would generate the most severe ground motions at the site at frequencies of engineering significance.

Activity 8.3.1.17.3.5.1 - Identify controlling seismic events. The objective of this activity is to identify underground nuclear explosions or 10,000-year cumulative-slip earthquakes that would produce the most severe ground motions at the site at frequencies of engineering significance. There may be more than one controlling seismic event because different events may generate the most severe ground motions in different frequency bands.

Activity 8.3.1.17.3.5.2 - Characterize ground motion from the controlling seismic events. The objective of this activity is to generate suites of strong-motion time histories and corresponding response spectra representative in amplitude, frequency content, and duration of site ground motions that could be generated by the controlling seismic events.

No progress during the reporting period; this was an out-year activity.

Forecast: Identification of controlling seismic events and development of seismic design inputs from them will take place in FY 1996 following completion of the probabilistic seismic hazard analysis (Study 8.3.1.17.3.6). It is anticipated that the study plan for this study will be revised to address fault displacement in addition to ground motion.

3.13.8 Study 8.3.1.17.3.6 - Probabilistic Seismic Hazards Analyses

The objective of this study is to quantify the probability for experiencing ground motions of varying degrees of severity that might result from earthquakes of varying magnitude and distance from the site. Probabilistic hazard estimates will also provide information needed to assess the credibility of postulated accidents at the repository that might lead to releases of radioactive materials.

Activity 8.3.1.17.3.6.1 - Evaluate earthquake sources. The objective of this activity is to determine average rates for earthquake recurrence as a function of magnitude for the southern Great Basin to a distance of about 100 km from the site, and then to apportion these rates onto active faults and subregional seismic source zones.

Activity 8.3.1.17.3.6.2 - Evaluate ground motion probabilities. The objectives of this activity are to estimate the probability of exceeding given ground-motion levels at the site; and to integrate contributions to that probability from all identified earthquake sources that could generate potentially damaging ground motion at the site.

Project seismologists completed the study plan for these activities in September 1994. The study plan describes how the methodology presented in Seismic Topical Report I (DOE, 1994n) will be implemented. Seismic source, fault displacement, and ground motion inputs to the hazard analysis will be developed by experts or teams of experts through interpretation of the available data. Workshops will facilitate the presentation of data to the experts and interactions among the experts. The goal is to establish a range of interpretations that is consistent with the data and to document the basis for the interpretations and assessments of uncertainty.

Forecast: Pending approval of the study plan in early FY 1995, the Probabilistic Seismic Hazards Analysis will be initiated during FY 1995. The USGS will assemble data packages which groups of national experts will use to assess seismic source characterization, ground motion attenuation, and faulting potential through the proposed critical facilities. Data-needs workshops will be held in mid FY 1995 for both ground motion and fault displacement hazards. Follow-up workshops on data interpretation and expert elicitation will

be held in early FY 1996. The final hazard calculations and final report will be completed during FY 1996.

3.13.9 Study 8.3.1.17.4.1 - Historical and Current Seismicity

The objective of this study is to compile information on reported and instrumentally recorded earthquakes that characterize the earthquake potential near Yucca Mountain. This information will be used to help identify and characterize potentially relevant earthquake sources for the deterministic hazard analysis and potentially contributing earthquake sources for the probabilistic hazard analysis; to develop regional earthquake ground-motion models; and to determine local-geologic and depth-of-burial effects on ground motion at the site.

Activity 8.3.1.17.4.1.1 - Compile historical earthquake record. The objective of this activity is to compile a record of historical seismic events in the southern Great Basin or within 100 km of Yucca Mountain which will indicate whether each cataloged seismic event is thought to be a natural earthquake, induced earthquake, underground nuclear explosion, cavity collapse, or blast. For potentially damaging earthquakes ($M \geq 5.5$) in the study region, available information will be compiled on ground-motion intensity, availability of strong-motion records, and extent and style of faulting.

Because past ground motion is one of the best indicators of future ground motion, characterization of historical seismicity within the southern Great basin is part of the Yucca Mountain study plan. An earthquake catalog containing basic information about seismic activity within 200 km of the Exploratory Studies Facility since 1868 (the year of the earliest reported earthquake in the southern Great Basin) was compiled. The effects of earthquakes are reported as Modified Mercalli intensities.

The strongest felt earthquake in this interval was the Little Skull Mountain earthquake of June 1992; intensity Modified Mercalli intensities-VII was recorded at the Field Operations Center on the Nevada Test Site. The average maximum intensity for the region is estimated to be V-VI (range II-VII). Except for the Little Skull Mountain earthquake, the epicenter of which was only 20 km southeast of Yucca Mountain, the higher reported earthquake intensities were produced by large earthquakes at least 150 km from Yucca Mountain.

Aftershock modeling suggests that current levels of seismicity at the Nevada Test Site are normal background and will persist. This work is reported by Gross and Jaume (in prep.).

Forecast: The historical seismicity investigation is complete at the end of FY 1994. The methodology of experimental efforts to topple precarious rocks will be documented in a report during the first quarter of FY 1995. The results of field, lab, and computer tests will be used to quantify the constraints on ground motion provided by precarious rocks. A final report, due June 30, 1995, will document the seismic hazard implied by the existence of numerous precarious rocks at Yucca Mountain.

Activity 8.3.1.17.4.1.2 - Monitor current seismicity. The objective of this activity is to provide empirical information on how often earthquakes are currently occurring in the southern Great Basin; what the orientation, depth, and style of faulting are; how seismic wave amplitudes scale with magnitude and attenuate with distance in the region; and how ground motions vary with depth and with surface geology in the site area.

A reversed seismic refraction profile was recorded along a line about 100 km long between the Non-Proliferation Experiment (a 1 kt conventional explosion) on the northern Nevada Test Site and a smaller shot (3,200 lb conventional explosion) at Ryan, California, in September 1993. Forty-six portable instruments (almost all equipped with 3-component seismometers) were deployed along the line and in fan geometry through Crater Flat, Jackass Flat, Amargosa Valley, and Death Valley; 28 permanent stations of the Southern Great Basin Seismic Network provided additional coverage.

The wide separation of the reversed profile permitted determination of P-wave velocity to greater depths (about 5 km) than was possible in earlier studies. First arrival times from these explosions were used to model the velocity structure of the upper crust near Yucca Mountain. Early P-wave arrivals at distances of 58-81 km from Non-Proliferation Experiment suggest a block of material which produces a high velocity (near 6.8 km/sec) in both Non-Proliferation Experiment-Ryan and in east-west directions; and which lies below 3 km depth and extends at least to 5 km deep beneath the western part of Yucca Mountain and the eastern part of Crater Flat. The exact nature and geometry of this body is unclear; it may be an equant body of cooled basaltic magma.

There is no indication of anomalously low-velocity material, suggesting molten or near-molten magma, at shallow depth below Yucca Mountain or in southern Crater Flat.

The monitoring network was upgraded to provide continuous recording in digital format. Hardware, software, and personnel requirements of this system were defined. Twelve upgrade sites were selected, and environmental review of sites on the Nevada Test Site, in Crater Flat, and near Bare Mountain was requested. Sites for microwave telemetry nodes at Shoshone and Echo Peaks were selected. The installation of a strong-motion array is waiting for USGS requisition of hardware.

Forecast: Any seismic activity associated with tunnel boring at the Exploratory Studies Facility will be monitored by the six-station digital network at Yucca Mountain, and up to six portable instruments placed in the tunnel itself. Monitoring of seismic activity in Rock Valley will continue. Software will come into use which routinely determines focal mechanisms for earthquakes detected by the CUSP system. In FY 1995 eighteen additional digital stations will be installed; complete necessary telemetry to receive data at University of Nevada, Reno Seismic Laboratory; install remaining computer hardware to record data from the network; and set up a routine process to produce a seismic catalog and archive events and data continuously recorded by the seismic network.

Activity 8.3.1.17.4.1.3 - Evaluate potential for induced seismicity at the site. The objective of this activity is to evaluate the potential for human activity to significantly perturb

natural seismic hazard at the site by inducing seismicity at or near the site. To date, the human activities that have been identified as having a potential to induce seismicity in the site region are the impoundment of Lake Mead, the testing of nuclear devices at the Nevada Test Site, and mining the repository itself.

No progress during the reporting period; this was an out-year activity.

Forecast: In FY 1995 Project seismologists will monitor possible seismic activity associated with tunnel boring.

3.13.10 Study 8.3.1.17.4.2 - Location and Recency of Faulting Near the Prospective Surface Facilities

The objective of this study is to identify a site in Midway Valley sufficiently large for surface facilities in which significant Quaternary faults are absent.

Surface and near-surface geologic data on the chronostratigraphic and structural relations of the Quaternary and Tertiary deposits, and Tertiary bedrock, were evaluated. Surficial geology of the study area was mapped, soils in 30 pits were described and correlated, and two trenches were excavated and mapped to investigate faults near the Reference Conceptual Site. The bedrock geology and faults of Exile Hill, along the west side of the Reference Conceptual Site, were mapped at 1:6000.

The dominant tectonic features in Midway Valley are the north-trending, westward-dipping normal faults along the margins of the valley: The Bow Ridge fault on the west, and the Paintbrush Canyon fault on the east. The maximum apparent vertical stratigraphic separation on these faults is about 220 m and 515 m respectively, but the net slip is not well constrained. Trenches across these faults show that both moved several times during middle-to-late Quaternary time; the most recent displacements were in late Pleistocene. Displacements per event range from 5 to 20 cm on the Bow Ridge fault, and from 20 to 85 cm on the Paintbrush Canyon fault. No evidence was found that suggested Quaternary strike-slip faulting along other, northwest-striking, faults in the Midway Valley area.

Geophysical (resistivity, seismic reflection, seismic refraction, gravity, and ground magmatic), borehole, and trench data suggest that a zone of normal bedrock faults, similar to those along the east flank of Yucca Mountain, exists in Tertiary strata beneath Midway Valley.

Surface and trench mapping clearly demonstrate the absence of any significant late Quaternary faults at the Reference Conceptual Site. Two north- to northeast-trending zones of extension fractures were identified in middle-to-late Quaternary colluvial and alluvial deposits, but no displacements as large as 5 cm were found in sedimentary deposits that are older than 100 ka. Therefore, no significant Quaternary faults, as defined by DOE (1988) are present beneath the Reference Conceptual Site.

Activity 8.3.1.17.4.2.1 - Identify appropriate trench locations in Midway Valley. The objective of this activity is to identify appropriate trench locations at proposed locations for repository surface facilities that are important to safety through detailed geologic mapping and remote sensing studies. The recommended locations will be used in trenching investigations in Activity 8.3.1.17.4.2.2.

This activity is complete.

Activity 8.3.1.17.4.2.2 - Conduct exploratory trenching in Midway Valley. The objectives of this activity are to investigate the possible occurrence of late Quaternary surface fault rupture in the vicinity of planned surface facility locations important to safety and to identify sites without evidence of significant late Quaternary faulting. This activity will provide input into the location and design of surface facilities important to safety, particularly those associated with waste handling.

Dominant tectonic features in Midway Valley are north-trending, west-dipping normal faults that bound the Exile Hill-Midway Valley structural block: the Bow Ridge fault on the west, and the Paintbrush Canyon fault on the east. Trenches across displaced Quaternary sediments show several middle-to-late Quaternary surface-faulting events on these faults. Northwest-trending strike-slip faults in the Midway Valley apparently do not displace Quaternary deposits.

A zone of faulting, similar to that on the east flank of Yucca Mountain, exists in Tertiary strata under Midway Valley. Bedrock faults near the Exploratory Studies Facility include both normal and strike-slip faults. Geologic and trench mapping clearly shown the absence of significant late Quaternary faults at the site for the prospective surface facilities important to safety.

Forecast: The final report for this activity will be completed the second quarter of FY 1995. This report represents the completion of this study.

3.13.11 Study 8.3.1.17.4.3 Quaternary Faulting Within 100 km of Yucca Mountain, Including the Walker Lane

The objective of this study is to identify Quaternary faults within 100 km of Yucca Mountain; and to characterize faults capable of future earthquakes with magnitude such that associated ground shaking could impact design or affect performance of the waste facility.

Because of its proximity to the repository site, the Bare Mountain fault was identified for detailed study. The objective of this activity is to evaluate the potential for ground shaking associated with movement along the Bare Mountain fault zone by estimating the age of most recent faulting, the recurrence interval of surface faulting, and the amount of slip associated with past faulting. Work on the fault has been limited to a trench at Tarantula Canyon, because permits for two additional trenches and five additional soil pits have been pending for more than a year.

Based on work at the one site, clear evidence is lacking for Holocene or latest Pleistocene faulting along the Bare Mountain fault zone. The activity rate of this fault is very low, 0.015 mm/yr or less, and the age of the most recent surface faulting event, 100,000 years, may be significantly older than previously thought. This event, characterized by approximately 1.5 m of displacement, is the only surface-faulting event at the Tarantula Canyon site in the last several hundred thousand years. Uranium series dates on $CaCO_3$ fault infilling are pending.

Activity 8.3.1.17.4.3.1 - Conduct and evaluate deep geophysical surveys in an east-west transect crossing the Furnace Creek fault zone, Yucca Mountain, and the Walker Lane. The objectives of this activity are to identify and locate potential seismic source zones, including possible through-going extensions of the Walker Lane, beneath the Oligocene-Miocene cover of the Yucca Mountain area; determine width and subsurface geometry of such extensions and of the Furnace Creek fault zone and the relation of these features to detachment faults and to Quaternary faults; and to evaluate the postulated incipient rift zone at Crater Flat; to characterize the crustal velocity structure and define lateral inhomogeneities in that structure in the Yucca Mountain area; to trace the 5- and 10-s events found on Death Valley COCORP profiles through the Yucca Mountain region and, if possible, to trace reflections from the upper and lower carbonate aquifers, the Precambrian-Cambrian Pahrump Group and Noonday Dolomite, and the Proterozoic basement across the Furnace Creek fault and through the area of the projected northwest continuation in the subsurface of the Las Vegas Valley shear zone; to identify differences in mass caused by variation in source lithology in the upper few kilometers of the crust, and correlate those sources with reflections obtained in the seismic reflection survey, or with conductivity features obtained in the magnetotelluric survey; to identify differences in magnetic field caused by sources in the upper few kilometers of the crust and correlate those sources with reflections obtained in the seismic reflection survey, or with conductivity features obtained in the magnetotelluric survey; to characterize conductivity structures of crust in the Yucca Mountain region, focusing in particular on the conductivity signature of the Walker Lane and Walker Belt, and if possible, trace the signature into the subsurface of conductive units such as the Eleana Formation or nonconductive units such as the lineated and mylonitized gneisses (lower plate?) of the northern Amargosa Desert, and to correlate these features at their offsets with Quaternary faults; and to provide data for analysis to determine if buried magma bodies are present in the vicinity of Yucca Mountain.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.17.4.3.2 - Evaluate Quaternary faults within 100 km of Yucca Mountain. The objectives of this activity are to establish the abundance, distribution, and geographic orientation of known and suspected Quaternary faults within 100 km of the site; to characterize Quaternary and Holocene fault and fracture pattern within 100 km of the site and, if feasible, to relate that pattern to regionally important wrench fault systems, including the Walker Lane, the Death Valley-Furnace Creek fault zone, and the Mine Mountain-Pahranagat shear zone; to characterize Quaternary faults within 100 km of the site whose apparent length or recurrence rate indicate potential for future earthquakes of magnitude sufficient to affect design or performance of the waste facility; to evaluate the recurrence history of that part of the Death Valley-Furnace Creek fault zone within 100 km of the site; to identify fault scarps

within 100 km of the site that may have been overlooked during conventional geologic field surveys and that may not have been apparent on conventional vertical aerial photography; to verify the existence and age of scarps in the Nevada Test Site area that were detected by low-sun-angle photogeologic interpretation; and to determine whether the Beatty scarp originated through tectonic or fluvial processes, or both, the nature of the movement along the scarp, if tectonic, and the age of the scarp.

Preliminary studies suggest late Quaternary slip rates for the Furnace Creek fault that are much higher than previously reported. At one site along the Death Valley fault, data suggest an average vertical slip rate of 3 to 5 mm/year for the last several thousand years. Along the Furnace Creek fault, data indicate an average lateral slip rate of 5 to 12 mm/year over the last several tens of thousands of years. Klinger and Piety (in prep.) will describe late Quaternary slip rate estimates for the Death Valley and Furnace Creek faults, and a paper will be presented at the 1994 Geological Society of America Annual Meeting.

A map and accompanying report on a preliminary compilation of known and suspected Quaternary faults within 100 km of Yucca Mountain (Piety, in prep.) has completed review and will be released as a USGS open-file report.

Activity 8.3.1.17.4.3.3 - Evaluate the Cedar Mountain earthquake of 1932 and its bearing on wrench tectonics of the Walker Lane within 100 km of the site. The objective of this activity is to evaluate the relevance of the 1932 Cedar Mountain earthquake to potential sources of ground shaking and rupture in that part of Walker Lane within 100 km of Yucca Mountain.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.17.4.3.4 - Evaluate the Bare Mountain fault zone. The objectives of this activity are to evaluate the potential for ground shaking associated with future movement along the Bare Mountain fault zone; to estimate the age of the most recent faulting on the Bare Mountain frontal fault; to estimate the recurrence intervals of faulting; to determine the nature and age of faulting within the fault complex east of the frontal zone, and to determine the nature of tectonic control of the location and orientation of the main wash in Crater Flat; and to determine the subsurface configuration of fault zones.

The Bare Mountain fault bounds the eastern flank of the first mountain range west of Yucca Mountain. Geologic mapping and early trench work indicate that the Bare Mountain fault zone has a low rate of activity and has not been active in the Holocene (Anderson and Klinger, in prep.).

Activity 8.3.1.17.4.3.5 - Evaluate structural domains and characterize the Yucca Mountain region with respect to regional patterns of faults and fractures. The objectives of this activity are to map faults and lineaments within 100 km of the site and identify those with geomorphic expression indicative of Quaternary faulting, to classify the area into subareas (domains) containing relatively homogeneous fault and lineament, to map the areal extent of desert varnish coating, and to identify areas of suspected hydrothermal alteration.

No progress during the reporting period; this was an out-year activity.

Activity 8.3.1.17.4.3.6 - Analyze rotation (drag) of bedrock along or over suspected wrench faults based on rotation of paleomagnetic declinations. The objective of this activity is to determine the spatial and temporal patterns of oroflexure bending based on rotation of paleomagnetic declinations.

No progress during the reporting period; this was an out-year activity.

Forecast: Seismic reflection data, which will allow the objectives of Activity 8.3.1.17.4.3.1 to be partially addressed, are being gathered during the early part of FY 1995 under Study 8.3.1.4.2.1. The major activities under this study are scheduled for completion in FY 1995. They will better define the age and amount of recent offset on the Death Valley and Furnace Creek faults. Reconnaissance geologic studies will evaluate significant known and suspected Quaternary faults within 50 km of Yucca Mountain, including faults in the Amargosa Valley and Ash Meadows area. Assuming that permits will be obtained, additional trenches will be excavated on the Bare Mountain fault, and the final report completed.

3.13.12 Study 8.3.1.17.4.4 - Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones

The objective of this study is to evaluate the potential for ground motion resulting from future movement of Quaternary strike-slip faults east and south of the site area.

Activity 8.3.1.17.4.4.1 - Evaluate the Rock Valley fault system. The objective of this activity is to determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Rock Valley fault system. Estimate the total displacement, including strike-slip and dip-slip components, of Quaternary datums.

Because the Rock Valley fault zone lies only about 25 km from Yucca Mountain, its structural affinities were investigated to assess the zone as a potential source of large earthquakes. Evaluation of the literature, geophysical data, and air photos lead to the following conclusions. The physiographic feature, Rock Valley, resulted from latest Miocene deformation that was principally vertical, and had a north-directed component of extension. Primarily Pleistocene deformation included both uplift in the east end of the valley, and subsidence in the valley south of Skull Mountain and in Frenchman Flat. It is suggested that the Rock Valley fault zone is a tectonic boundary that penetrates the crust and separates Paleozoic carbonate terranes to the south from Neogene volcaniclastic terranes to the north, as a crustal slab which is dragged by lateral flow in the upper mantle. A manuscript proposing this tectonic model for the Rock Valley fault zone has been prepared for publication (O'Leary, in prep.).

Activity 8.3.1.17.4.4.2 - Evaluate the Mine Mountain fault system. The objective of this activity is to determine the location, spatial orientation, length, width, Quaternary

recurrence rate, and the location, amount, and nature of Quaternary movement of the Mine Mountain fault system.

The Mine Mountain fault is actually a zone comprising two N35°E-striking sub-parallel faults that are separated by as much as 200 m. These parallel faults interconnect and splay. The only clear offset of units mapped along the fault zone is at Mine Mountain, where the Tiva Canyon Member of the Paintbrush Tuff is displaced in a left-lateral sense 1.2 km. Northeast of Mine Mountain, in Yucca Flat, and southeast, in Mid Valley, the fault zone is buried by alluvium. On the basis of field work completed to date, the Mine Mountain fault zone does not appear to pose a seismic hazard, as there is no clear evidence of Pleistocene or Holocene activity, and because of the absence of long, single fault planes.

Activity 8.3.1.17.4.4.3 - Evaluate the Stagecoach Road fault zone. The Stagecoach Road fault evaluation has been transferred to Study Plan 8.3.1.17.4.6 (Quaternary Faulting in the Site Area). (See Section 3.13.14.)

Activity 8.3.1.17.4.4.4 - Evaluate the Cane Spring fault system. The object of this activity is to determine the location, spatial orientation, length, width, Quaternary recurrence rate, and the location, amount, and nature of Quaternary movement of the Cane Spring fault system.

No progress during the reporting period; this was an out-year activity.

Forecast: Trenches will be excavated in Rock Valley in the first quarter of FY 1995. Mapping and interpretation of trench exposures will provide data on northeast-striking faults which will be available for use in seismic hazard analysis.

3.13.13 Study 8.3.1.17.4.5 - Detachment Faults at or Proximal to Yucca Mountain

The objectives of this study are to supply information pertaining to distribution, displacement rate, and age of detachment faults proximal to Yucca Mountain. Key questions regarding detachment faults are whether they represent a significant earthquake source, and whether they conceal a significant earthquake source at depth. To resolve both questions, activities are focused on resolving the Quaternary behavior of postulated detachment faults.

Activity 8.3.1.17.4.5.1 - Evaluate the significance of the Miocene-Paleozoic contact in the Calico Hills area to detachment faulting within the site area. The objectives of this activity are to determine whether the contact of Miocene volcanic rocks on Paleozoic strata is tectonic or depositional; if tectonic, to determine Quaternary activity, if any, of the possible detachment fault; and, if Quaternary, to determine the direction and age of movement, attitude of fault plane, and nature of deformation of the Miocene (upper plate?) sequence.

A final report (Simonds, in prep.[a]) was submitted for USGS review, and a second manuscript (Simonds, in prep.[b]) has been submitted for publication in a USGS circular. As previously reported, these reports conclude that the Paleozoic rocks are not structurally

detached from the overlying Miocene rocks, thus eliminating the possibility that a detachment fault at that horizon constitutes a source of seismicity for consideration in repository design.

Activity 8.3.1.17.4.5.2 - Evaluate postulated detachment faults in the Beatty-Bare Mountain area. The objective of this activity is to determine if postulated detachment faults in the Beatty Bare Mountain have been active in the Quaternary.

Additional microprobe data from metamorphic minerals were analyzed, and thermodynamic calculations were performed to define mineral geobarometry and thermometry. Analytical results and thermodynamic calculations were included in a manuscript (Hoisch, in prep.).

The Geologic Map of the East of Beatty Mountain has been submitted for USGS Director's approval. The geologic map of Big Dune quadrangle is in USGS review. Field work continued in the Beatty Mountain quadrangle.

Preliminary results of this activity indicate that two low-angle ("detachment") faults are present at the northern end of Bare Mountain. The lower fault, which has substantial displacement, juxtaposes metamorphosed Paleozoic rocks against unmetamorphosed rocks. The upper fault deforms Miocene volcanic rocks in a series of tilted blocks. The geometry of the faults and the distribution of extended upper plate rocks suggest that this detachment fault system does not extend to the east beneath Yucca Mountain. These findings are an important contribution to tectonic models for the Yucca Mountain region.

Activity 8.3.1.17.4.5.3 - Evaluate the potential relationship of breccia within and south of Crater Flat to detachment faulting. The objective of this activity is to determine whether breccias tectonically emplaced on low-angle surfaces beveled across the Paleozoic and younger strata are slide masses or near-surface parts of a detached upper plate; and, if either, how they relate to postulated Quaternary detachment faulting.

No progress during the reporting period; this was an unfunded activity.

Activity 8.3.1.17.4.5.4 - Evaluate postulated detachment faults in the Specter Range and Camp Desert Rock areas. The objective of this activity is to determine whether the basal contact of the Horse Spring Formation is depositional or tectonic; and, if tectonic, to determine whether movement was Quaternary or older, and if Quaternary, to determine the direction and amount of offset, the amount of extension, and the style of intentional deformation of the upper plate.

Reconnaissance investigations were conducted in Camp Desert Rock area and the Specter Range; information so derived was evaluated with information on the Rock Valley fault zone, and a report (Simonds, in prep.[c]) is in review.

Preliminary results indicate that the postulated fault in the Camp Desert rock area is not a detachment. Alternatively, it is proposed that the fault is a strike-slip fault involving drag

folding. Although detachment faults have been examined in the Specter Range, none have been identified near Yucca Mountain.

Activity 8.3.1.17.4.5.5 - Evaluate the age of detachment faults using radiometric ages. The objectives of this activity are to determine if the subdetachment basement and the Bare Mountain massif cooled through the blocking temperatures of zircon and apatite during the Quaternary period; and to determine if the Northern Amargosa core complex cooled through the blocking temperatures of muscovite and biotite during the Quaternary period.

Ages are being estimated by $^{40}Ar/^{39}Ar$, U/Pb, and fission-track dating of zircons. The ages so derived will provide needed information on the timing and recency of tectonic activity in the Yucca Mountain area. Six of ten $^{40}Ar/^{39}Ar$ analyses and the U/Pb analyses have been completed. Fission-track dating has begun.

Forecast: A report (Simonds, in prep.[d]) will be submitted for USGS Director's approval. Field work will continue in the Beatty Mountain quadrangle to document the geometry and history of detachment faults in northern Bare Mountain. Analysis of the thermobarometry of the lower plate rocks at Bare Mountain will continue, and the results of geochronology will be integrated.

3.13.14 Study 8.3.1.17.4.6 - Quaternary Faulting Within the Site Area

The objectives of this study are to identify and characterize Quaternary faults that intersect or project toward the surface facility, repository, or controlled area; and to identify and characterize Quaternary faults at the site whose length or recurrence rate suggest a potential for future earthquakes with magnitudes such that associated ground shaking could affect design or performance of the waste facility.

Activity 8.3.1.17.4.6.1 - Evaluate Quaternary geology and potential Quaternary faults at Yucca Mountain. The objectives of this activity are to synthesize and evaluate data pertaining to location, orientation, length, width, Quaternary recurrence rate, and location, amount, and nature of Quaternary movement of faults within the site area; and to identify unrecognized faults in the site area.

A USGS map report (Simonds et al., in prep.) compiles geologic, geomorphic, and stratigraphic age information on all major faults in the Yucca Mountain area and categorizes them as known Quaternary, suspected Quaternary, or bedrock fault segments. Known Quaternary segments disturb or offset surficial deposits, commonly several times; suspected Quaternary segments do not clearly offset surficial deposits, yet Quaternary movement is likely; bedrock segments cut Miocene units but leave no direct evidence of Quaternary movement. Faults principally show normal (down to the west) movement, and most show a small amount of left-oblique slip. Faults on the west side of Yucca Mountain appear interconnected and contain Quaternary or suspected Quaternary segments up to 10 km long. Faults on the east side contain Quaternary segments less than 3 km long.

Activity 8.3.1.17.4.6.2 - Evaluate age and recurrence of movement on suspected and known Quaternary faults. The objectives of this activity are to determine through trenching and trench wall mapping the location, spatial orientation, length, width, Quaternary recurrence rate, interconnections at the surface, and the location, amount, and nature of Quaternary movement of the Windy Wash, Solitario Canyon, Ghost Dance, and Paintbrush Canyon faults and other suspected or possible Quaternary faults within the site area; and to determine through trenching and dating the age, amount, and nature of offset and the recurrence history of the Bow Ridge fault system and to evaluate that information in context with data contributed by other studies on the age, nature, and origin of fracture coatings and fissure fillings deposited within that zone.

Project scientists continued to examine the history of movement on known or suspected Quaternary faults. Special emphasis was placed on obtaining age dates to constrain the timing of fault movement and on synthesizing and reporting the results of previous work.

Preliminary U-series results were obtained on three samples (twelve aliquots) of carbonate (rhizoliths and laminar veins) bracketing the major fissuring event along the Solitario Canyon fault in Trench 8. The rhizoliths and vein carbonates within the fissure provide minimum ages for rupture of about 30 and 15 ka, respectively, and vein material exterior to the fissure believed to be associated with the next oldest event provides a maximum age of approximately 100 ka. Additional materials that have not yet been analyzed may provide further constraints.

Available U-series data were compiled and ages were estimated for samples from fault-associated trenches on the east side of Yucca mountain. Available thermoluminescence data were also compiled, and all geochronological data were plotted on trench logs. In general, good agreement exists between the two techniques where they can be compared.

Paces, et al. (1994) describe U-series disequilibrium and thermoluminescence age estimates for pedogenic deposits which bracket rupture events on the Paintbrush Canyon, Bow Ridge and Stagecoach Road faults. The internally consistent ages are interpreted to date depositional events or episodes of pedogenic carbonate mobility that can be used to establish a seismic history. The evaluation of seismic hazards at Yucca Mountain ultimately depends on this type of information.

A team of geochronologists, geochemists and Quaternary geologists developed an integrated approach to obtaining a defensible geochronological framework for the Quaternary surficial deposits at Yucca Mountain. The approach focuses on integrating multiple analytical methods including U-series disequilibrium, thermoluminescence, in situ cosmogenic nuclides, radiocarbon and tephrochronology applied to a variety of alluvial and colluvial surficial deposits in various geomorphological settings around Yucca Mountain. This approach will serve to guide new geochronological studies in FY 1995.

Several reports were completed, describing work on site faults. Key progress that was reported includes:

- The Stagecoach Road fault exhibits 2-4 late Quaternary events with slip rates of 0.02-0.05 mm/yr.

- The Bow Ridge fault shows evidence of a low but persistent level of late Quaternary activity. Slip rates are 0.001-0.003 mm/yr; this information is important because the fault crosses the Exploratory Studies Facility North Ramp.

- Results for the Windy Wash fault indicate slip rates on the order of 0.03 mm/yr.

- Preliminary logs of both walls of a trench on the Fatigue Wash fault, on the west side of Yucca Mountain, show 4 or 5 mid-to-late Quaternary fault events; one fissure contains basaltic ash. Samples from this site were collected for U-series dates to constrain the formation of the fissures and to compare with ash samples found in other trenches.

- Scarp degradation studies on northern Windy Wash and southern Solitario Canyon faults indicate that exposed sections of the fault scarps are more than 20,000 years old.

- Logs of four trenches on the Ghost Dance fault indicate no late Quaternary activity on this fault. Samples were submitted for cosmogenic dating of bedrock exposed on fault line scarps on Whaleback and Antler ridges.

Other progress includes:

- Logs of trench walls 1,2, and 4 at Busted Butte, on the southern Paintbrush Canyon fault, were completed. Logging was begun at modified Trench A1 on the northern Paintbrush Canyon fault.

- Requests were formally submitted for permission to excavate two or three new trenches on Crater Flat fault.

- Topographic profiles were surveyed at all sites where trenches are being logged (i.e., at all Quaternary faults in the site area, and at Stagecoach Road, Solitario Canyon, Fatigue Wash, and Windy Wash faults). Morphologic analyses can provide a means of estimating scarp age.

Project geologists concluded, after extensive research, that the scarps along part of the Solitario Canyon and northern Windy Wash fault traces have not been appreciably enhanced by earthquake-induced surface rupture during at least the last 20 ka.

The age of the scarps was determined using cosmogenic dating of rock samples collected from near the top and the base of the scarp face at four sites along each scarp. Additional samples were collected from the middle of the scarps at sites where the height of the scarp was greater than 1 m. The concentration of cosmogenic ^{14}C in the samples was determined using accelerator mass spectrometry analysis. Results of these analyses indicated

that the samples were saturated with respect to cosmogenic ^{14}C. Since saturation is achieved at approximately 20 ka, the scarps have a surface exposure age >20 ka. One of the samples taken at the base of each scarp, however, yielded an age significantly younger than 20 ka, suggesting localized erosion at the base of the scarps at these specific sites during the Holocene.

The samples at the base of the scarp at the three other sites on each scarp yield saturated values, and geomorphic field studies along the scarps previously demonstrated that differential hillslope erosion was probably responsible for exposure of the scarps by exhumation of siliceous tertiary fault breccias, which are resistant in the dry, semiarid climate of Yucca Mountain. Thus, the topographically striking scarps, though they may appear similar to historic or Holocene fault scarps in other parts of the Basin and Range, are much older features that have been significantly influenced, or are the product of, hillslope erosion.

An abstract of a paper on these findings was published in Geological Society of America Abstracts (Harrington et al., in prep.).

A geomorphic study along the trace of the Ghost Dance fault across Antler and Whale Back ridges, led to an innovative application of cosmogenic dating techniques to determine the time since the last vertical displacement occurred along a segment of the fault. Because there is no exposed fault scarp present along the Ghost Dance fault, samples were collected from bedrock outcrops and the tops of large boulders along a topographic traverse from the ridge crest east of the fault to a bedrock outcrop across the fault trace. The sample sites were closely spaced where they are in proximity of the fault trace. Vertical displacement along the fault should result in erosion of material from the up thrown side of the fault and deposition of material on the down thrown side of the fault. Thus, younger exposure ages in close proximity to the fault when compared to exposure ages from bedrock outcrops at greater distances from the fault, would provide a minimum time since faulting occurred. The exposure ages of the sampled rock surfaces are being determined using accelerator mass spectrometry analysis of cosmogenic beryllium in the rock samples.

Forecast: In the next six months, reports on the Bow Ridge, Paintbrush Canyon, Solitario Canyon, Fatigue Wash, Windy Wash, and Ghost Dance faults will be completed. Field work will be conducted as needed to complete paleoseismic investigations of these faults, as well as of the Crater Flat fault. These results will be compiled into several summary reports which will be part of the seismic hazard analysis.

3.13.15 Study 8.3.1.17.4.7 - Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain

The objectives of this study are to provide data on distribution of mass, magnetic gradients, geoelectric features, and seismic velocities and reflections that will aid in evaluating the continuity of Quaternary faults where concealed by Holocene and late Pleistocene surficial deposits; to evaluate the data and its limitations; to evaluate the possibility that Quaternary faults exposed as high-angle faults at the site continue to depth as planar, high-angle faults, or

alternatively, flatten at depth and merge with one or more long-angle faults; and to provide information on continuity of rock units within the repository and controlled area to assist the investigation of site geology.

There are eight activities in this Site Characterization Plan section. Field geophysical surveys critical to, and analysis and assessment of, the subsurface geometry and concealed extensions of Quaternary faults are to be carried out under Study Plan 8.3.1.4.2.1. Geophysical surveys conducted for Study 8.3.1.4.2.1 will be examined as inputs for assessing concealed faults and subsurface geometries. The implications of subsurface geometry and concealed extensions of Quaternary faults will be addressed as part of the sensitivity studies associated with Study 8.3.1.17.3.6.

Forecast: There will be no study plan developed for this Site Characterization Plan section. A revision to Study Plan 8.3.1.4.2.1 will be made to incorporate this scope of work. The Design and Test Requirements Document will be revised to reflect this change.

3.13.16 Study 8.3.1.17.4.8 - Stress Field Within and Proximal to the Site Area

The objectives of this study are to provide data on ambient stress at the site and its immediate vicinity that will aid in evaluating most favored orientation and nature of future movement on faults within the site area, stability of potential pathways for radionuclide travel controlled by or related to fracture aperture, the stability of mined excavations, response of rock mass to thermal loading, and applicability of tectonic models. A secondary objective is to evaluate the potential relevance of paleostress data to prediction of future stress orientations.

Activity 8.3.1.17.4.8.1 through 8.3.1.17.4.8.4. No progress during the reporting period; these were out-year activities.

Forecast: A study plan for these activities will be developed during FY 1995.

3.13.17 Study 8.3.1.17.4.9 - Tectonic Geomorphology of the Yucca Mountain Region

The objective of this study is to document Quaternary uplift and subsidence within the Yucca Mountain region and to evaluate regional variation in the nature and intensity of Quaternary faulting.

Activities 8.3.1.17.4.9.1 through 8.3.1.17.4.9.3. Activities -.1 and -.2 define a work scope documented in the Extreme Erosion Topical Report and that is still in progress through the surface mapping performed under Study 8.3.1.5.1.4. The work scope for Activity -.3 is to be transferred to Study Plans 8.3.1.17.4.3 and 8.3.1.17.4.12.

Forecast: There will be no study plan developed for this Site Characterization Plan section. The work scope already has been, or will be, transferred to, and performed under, Studies 8.3.1.5.1.4, 8.3.1.17.4.3, and 8.3.1.17.4.12. The Site Design and Test Requirements Document will be revised to reflect this change.

3.13.18 Study 8.3.1.17.4.10 - Geodetic Leveling

The objective of this study is to evaluate possible historical and contemporary vertical displacements across potentially significant Quaternary faults within 100 km of Yucca Mountain. A secondary objective is to characterize the historical rate of uplift and subsidence in the Yucca Mountain region and evaluate the possible existence of tectonic boundaries, coinciding perhaps with the Walker Lane or with the Furnace Creek fault zone, that may separate domains with differing rates of uplift and subsidence.

Activities 8.3.1.17.4.10.1 through 8.3.1.17.4.1.0.3. In late May 1994, five original quadrilateral arrays (Trench 1, Trench 14, Solitario, Yucca Ridge, and Fran Ridge) and a new one (Stage, which had been set in 1991) were remeasured using the Global Positioning System. Each array straddles a fault; remeasurements are intended to document any horizontal movement on that fault segment. This was the first year that Global Positioning System was used; previously, electromagnetic distance measurements had been used. The resolution of Global Positioning System measurements is 1-2 cm; Global Positioning System measurements checked against the USGS baseline (on the Denver Federal Center), calibrated within 2 mm. Global Positioning System measurements on the arrays fell within the range of measurements obtained using electromagnetic distance measurements. Preliminary results indicate no apparent horizontal movement in comparison to past sets of measurements on these arrays.

Some net vertical elevation differences were noted in the vicinity of Little Skull Mountain after the June 1992 earthquake. Benchmark elevations along a 90+ km line, extending approximately from Beatty to Mercury, Nevada, have been measured six times since 1983; the most recent survey post-dates the 1992 Little Skull Mountain earthquake. To compare elevations, post-earthquake elevations were subtracted from elevations of each pre-earthquake survey. In all cases, pre-earthquake elevations in the vicinity of Little Skull Mountain, were higher than post-earthquake elevations. (No systematic changes were noted elsewhere.) Thus the Little Skull Mountain area appears to have down-dropped during the earthquake. As the mainshock of the earthquake involved dip-slip motion, down to the southeast, on a steeply dipping fault plane that projects to the surface near the Field Operations Center, and the Field Operations Center lies near the northwest edge of the region of elevation change, down-dropping of this area seems reasonable.

Forecast: The quadrilateral survey will be completed in November 1994 (delayed because of equipment failure in May 1994), and results for all quadrilateral measurements will be submitted. Geodetic leveling will then proceed; it will require about five months to complete.

3.13.19 Study 8.3.1.17.4.11 - Characterization of Regional Lateral Crustal Movement

The objective of this study is to evaluate rates and orientation of historical and current crustal strain based on analysis of existing data on seismicity, historical fault, offset, and creep in the Basin Range and at Yucca Mountain. The activity in this Site Characterization Plan section will receive and evaluate information from Study 8.3.1.17.4.10. No unique data are to be acquired by this study.

Forecast: There will be no study plan developed for this Site Characterization Plan section. This scope of work is to be transferred to Study 8.3.1.17.4.10. The Site Design and Test Requirements Document will be revised to reflect this change.

3.13.20 Study 8.3.1.17.4.12 - Tectonic Models and Synthesis

The objectives of this study are to synthesize data relevant to tectonics; to develop a model or range of models that establishes the causal relation between application of tectonic forces and formation of structures observed at Yucca Mountain and vicinity, to link observed rates of formation of structures with regional rates of crustal strain; to forecast changes in tectonic setting and the manner in which changes will affect both regional crustal strain rate and tectonic stability in the Yucca Mountain region, to estimate effect of changes on rate and nature of crustal strain at Yucca Mountain and vicinity, and to estimate future rate of tectonic processes at Yucca Mountain.

Activity 8.3.1.17.4.12.1 - Evaluate tectonic processes and tectonic stability at the site. The objectives of this activity are to synthesize gravity studies at Yucca Mountain and vicinity and define regional variations in mass, and attribute them, as appropriate, to variations in crustal thickness, degree of melting, shallow intrusions, distribution of specific stratigraphic units, and faults; to synthesize magnetic studies at Yucca Mountain and vicinity and define areal variations in magnetic field and relate them, as appropriate, to distribution of specific stratigraphic units, shallow intrusions, and subsurface configuration of faults; to evaluate regional extent of detachment faults, wrench faults, volcanic rocks belonging to the Death Valley-Pancake Range belt, regional pattern of oroclinal bending (oroflexing), regional extent of Miocene ash-flow tuffs and associated pyroclastic and epiclastic rocks, and regional extent of Paleozoic rocks known to be aquifers, aquitards, or to provide favored surfaces of detachment or thrusting; to synthesize and evaluate information pertaining to Quaternary wrench faulting in the Walker Lane (Las Vegas to Cedar Mountain), constrain, if possible, the rate of offset and recurrence interval of potentially significant faults (including the Bare Mountain fault and faults analogous to those near Cedar Mountain), and evaluate the applicability of this information to geologic hazards at the site; to synthesize and evaluate information pertaining to detachment faults at Yucca Mountain and vicinity and constrain the rate of displacement, subsurface configuration, and risk posed by this class of faults; to synthesize and evaluate information pertaining to normal (and north-trending oblique and strike-slip faults) at the site and vicinity, and possibly constrain aggregate strain rate, subsurface configuration, recurrence interval, and risk posed by this class of faults; and to synthesize and evaluate information pertaining to the northeast-trending left-lateral strike-slip

faults at the Nevada Test Site and vicinity, and constrain slip rate, recurrence interval, and risk posed by this class of fault.

Comment resolution on the Tectonic Models and Synthesis study plan was completed. Work continued on integrating and synthesizing geologic, tectonic, and geophysical data for the Yucca Mountain region, including preparation of the Death Valley tectonic synthesis map.

This work supplies the information with which tectonic models must be consistent. Current thinking on the process of crustal extension considers it a domainal process, localized within domains which may be coterminous with individual structural basins.

Activity 8.3.1.17.4.12.2 - Evaluate tectonic models. The objectives of this activity are to formulate a range of tectonic models that relate the nature and estimated rates (including bounding values) of Quaternary processes (volcanism, faulting, uplift, and subsidence, lateral strain, and possibly folding) of potential significance to design and performance of the repository at Yucca Mountain; to evaluate temporal changes in tectonic activity and resulting changes in fractures and other structural features of potential hydrologic significance at and in the vicinity of Yucca Mountain (relate tectonic cycle, if it exists, to tectonic model(s)); to ensure that assumptions, inferences, and conclusions concerning tectonic processes that are important to design and performance of the repository are consistent with tectonic models applicable to the site; and to ensure that uncertainty in the data, assumptions, and inferences concerning rates and nature of those tectonic processes that are important to design or performance of the repository is adequately reflected in conclusions about those processes.

Work continued on evaluating tectonic models by data synthesis, field examination, boundary element modeling, and literature analysis. Field review shows essentially no evidence of shallow (mid crustal) detachment faulting near Yucca Mountain (other than that at Bare Mountain). Boundary element modeling readily explains the structure of Yucca Mountain by through-the-crust normal faulting. The tectonic character of Yucca Mountain is sensitive to the behavior and geometry of major faults east and west of Yucca Mountain. A manuscript applying boundary-element modeling to Yucca Mountain has been submitted for publication in a USGS Circular (King and Janssen, in prep.).

Developing tectonic models of Yucca Mountains requires a better understanding of tectonic domains, and how the interaction of these domains in the upper, brittle, crust is controlled by deep-crustal or upper-mantle processes. Boundary element modeling and paleomagnetic data indicate that rotation of blocks has affected tectonic domains, including the Crater Flat domain of which Yucca Mountain is a part. This rotation may reflect activity in the Walker Lane belt, and thus Paleogene extension may control some of the younger deformation near Yucca Mountain.

Activity 8.3.1.17.4.12.3 - Evaluate tectonic disruption sequences. The objective of this activity is to evaluate disruption sequences involving faulting, folding, uplift and subsidence, and volcanism that are of potential significance to design or performance of the repository.

No progress during the reporting period; this was an out-year activity.

Forecast: A summary evaluation of tectonic models, boundary element modeling results, and tectonic processes at Yucca Mountain and in it geologic setting will be submitted to DOE in August 1995. Models will be refined and data will continue to be synthesized during the remainder of FY 1995, so that a revised model can be reported in FY 1996.

3.14 STUDY 8.3.1.20.1.1 - ALTERED ZONE CHARACTERIZATION

A new Work Breakdown Structure element has been established to cover this activity. The Site Characterization Program Baseline section was drafted during this reporting period. The study plan was assigned number 8.3.1.20.1.1. This study will cover altered zone characterization techniques and evaluation of thermal effects. A detailed outline for the study plan was completed and drafting begun.

The purpose of the Altered Zone study is to evaluate the effect of coupled thermal-hydrological-geochemical-geomechanical processes on the thermal evolution of the repository, the effect of the coupled processes on the composition of water that may enter the near-field environment, and determine how these coupled processes may influence the development of secondary minerals in the vicinity of the repository that will affect the source term.

Experiments were begun to evaluate the effect on water composition and secondary mineral development of water-rock interaction on vitric and vitrophyric rocks that occur in the near-vicinity of the repository. The experiments will determine the rates of reactions, the solid phases that form that could influence radionuclide transport, and the effect of reactions on water chemistry.

Computations to bound the effects of coupled hydrogeochemical processes were initiated at LLNL. These computations, conducted in collaboration with Los Alamos personnel, were intended to be reconnaissance studies, examining the effects of changes in permeability on water chemistry and heat transfer. The preliminary results of these studies are being written up.

Forecast: Experiments and code coupling activities will continue. The study plan will be completed. Relevant portions of Study 8.3.1.3.3.1, "Natural Analog of Hydrothermal Systems in Tuff," will be considered for incorporation to this study. Study Plan 8.3.1.3.3.1 has been eliminated as a result of the Site Characterization Plan work scope consolidation effort.

CHAPTER 4 - REPOSITORY DESIGN

This chapter reports progress in the design of the potential repository which consists of surface facilities, underground facilities, and shafts and ramps connecting the surface and underground facilities. In addition, when the repository is prepared for permanent closure, seals will be constructed for the shafts, ramps, and exploratory boreholes. The repository facilities will be designed to meet various functional and regulatory requirements, including those of NRC.

4.1 CONFIGURATION OF UNDERGROUND FACILITIES (POSTCLOSURE) (SCP SECTION 8.3.2.2)

A set of six drawings showing Exploratory Studies Facility/Repository interfaces was baselined. Development of repository layout concepts continued during the current reporting period, and was summarized in the initial Advanced Conceptual Design Summary Report (CRWMS M&O, 1994a). Several modifications to the baselined Exploratory Studies Facility/Repository interface layout were proposed in that document. In brief, the changes proposed include:

- Incorporation of the USGS Lynx, Rev. 01 geologic model, with additional M&O revisions incorporating latest drilling data, to define the repository emplacement block.

- Realignment of the horizontal and vertical orientation of the Exploratory Studies Facility main drift (which approximately parallels the Ghost Dance fault) in accordance with the M&O Lynx geologic model to enhance future repository constructability.

- Repositioning an extension off the Exploratory Studies Facility North Ramp to avoid several faults which are projected to cross near its original planned intersection with the ramp, and to better utilize the northern portion of the upper repository emplacement block.

- Minor redefinition of upper and lower block repository perimeter drift positions to correspond with the results of the M&O Lynx geologic model.

4.1.1 Design Activity 1.11.1.1 - Compile a Comprehensive List of All the Information Required From Site Characterization to Resolve This Issue

Some of the data needed from site characterization by the repository surface and subsurface design groups were identified. Values were assumed and placed in the Controlled Design Assumptions document (CRWMS M&O, 1994b) as part of the focused Advanced Conceptual Design approach. A preliminary list of the information needs has been compiled. A plan is being prepared to develop a comprehensive Repository Data Needs document.

Forecast: The identification and documentation of all data needs from site characterization will be made during FY 1995. The plan for a Repository Data Needs document is expected to be completed in January 1995, and the document is scheduled for completion in May 1995. A comprehensive data needs list for repository subsurface design will result from this effort. During this activity an evaluation of the level of confidence necessary in data values will begin. Site Characterization Plan Table 8.3.2.2-5 will be consulted as the starting point for this evaluation.

4.1.2 Design Activity 1.11.1.2 - Determine Adequacy of Existing Site Data

No progress during the reporting period; this was an unfunded activity.

Forecast: Efforts in this activity will begin during FY 1995 and will become an ongoing activity through most of the License Application Design. This effort involves an evaluation of the quantity and quality of currently available data, and subsequent reevaluation as new or additional data are received. The effort will end when all data necessary for the License Application are available.

4.1.3 Design Activity 1.11.1.3 - Document Reference Three-Dimensional Thermal/Mechanical Stratigraphy of Yucca Mountain

No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

4.1.4 Design Activity 1.11.1.4 - Preparation of Reference Properties for the Reference Information Base

The Reference Information Base is a controlled data base that provides summary data and information for use in site suitability evaluations, design and development activities, and Performance Assessment analyses.

A recent update to the Reference Information Base Table of Contents reflects the progress of defining the data requirements of the primary data users. During the reporting period, the Reference Information Base identified data needs to facilitate the preparation of Reference Properties for incorporation.

Forecast: The Technical Data Management Group will be concentrating Reference Information Base development efforts in two areas: implementing a plan to qualify some of the Reference Information Base data that have been identified as immediately necessary; and compiling newly-acquired qualified data to supersede existing unqualified Reference Information Base data items.

4.1.5 Design Activity 1.11.2.1 - Compile Waste Package Information Needed for Repository Design

To assess the impacts of a crushed tuff backfill on the near-field thermal environment, tests were conducted that are designed to help quantify the effective thermal properties of crushed tuff backfill. A second heat-up cycle was completed to examine the reproducibility of the behaviors observed during the initial cycle. Post-test analyses using the TOUGH2 code and a parameter estimation technique have been completed in an attempt to match the early-time data. In addition, a conduction-only code has been used to examine the cool-down data taken for both experiments. Post-test analysis results for effective thermal diffusivity show reasonable agreement among the various methods (Longenbaugh et al., in prep.). Moisture content and convective effects were shown to be important components of heat transfer in the crushed tuff. During decommissioning, chemical coatings were observed on the surfaces of some of the crushed tuff particles. Samples were taken and provided to LLNL for analysis.

Forecast: No activity is planned for FY 1995.

4.1.6 Design Activity 1.11.3.1 - Area Needed Determination

The emplacement area needed is typically and simplistically expressed by dividing the total initial thermal output of the waste inventory by the local, or unit, thermal load. The lower the thermal load, the greater the area needed for emplacement. Total area needed is the emplacement area plus that for development, operations, performance confirmation, and any other needs.

A design basis thermal load has not yet been selected by the Project. However, the Project has made an assumption that the surface and subsurface configurations are to accommodate thermal loading options for both a primary, high thermal load of 225 to 282 kW/ha (80 to 100 MTU/acre, 91 to 114 kW/acre) and an alternative, low thermal load of 69 to 99 kW/ha (25 to 35 MTU/acre, 28 to 40 kW/acre) (CRWMS M&O, 1994b). This assumption is related to an average fuel of a given age and burnup. It has also made an assumption that the repository will be limited to the primary area (CRWMS M&O, 1994b) as defined in Mansure and Ortiz (1984).

The current concept for a repository layout (CRWMS M&O, 1994a) can accommodate a thermal load of 82 MTU/acre or greater within the primary emplacement area located west of the Ghost Dance fault. The combination of the primary emplacement areas east and west of the Ghost Dance fault can accommodate a thermal load as low as 66 MTU/acre. Limiting the repository to the primary area for low thermal loads means that disposal of 70,000 MTU will require thermal management of waste during emplacement. At 69 to 99 kW/ha (28 to 40 kW/acre), approximately 26,400 to 37,400 MTU can be disposed of within the primary area without thermal management.

Forecast: Work during FY 1995 will deal with determining the actual area available for emplacement and thermal management during waste emplacement to make more use of

the available area, especially for low thermal loads. As an example of thermal management, ventilation after emplacement will be studied as a means of dissipating heat to allow 70,000 MTU to be placed within the available area for low thermal loads.

4.1.7 Design Activity 1.11.3.2 - Usable Area and Flexibility Evaluation

The Project has made an assumption that the repository will be limited to the TSw2 geologic unit within the primary area (CRWMS M&O, 1994b). The primary area is as defined by Mansure and Ortiz (1984). This assumption has limited the scope of this design activity to investigation within the primary area.

An analysis (CRWMS M&O, 1994c) was performed during the period to further define zones acceptable for waste emplacement within the limits established by the key assumption. The analysis utilized output from the three-dimensional Lynx Computer System software that used the USGS geologic model as its basis. The software was qualified for use on quality affecting work on May 25, 1994. The analysis considered geotechnical, thermal, and hydrologic characteristics of the rock and their application to repository construction. The analysis established vertical and horizontal limits on repository development, mostly expressed in terms of standoff distances from certain features, and it generally concluded that all of the TSw2 unit may be suitable for repository construction.

Forecast: Work on refinement of the repository horizon definition will continue throughout FY 1995. Thermal loading alternatives may require consideration of potential expansion areas using data from expanded site characterization activities.

4.1.8 Design Activity 1.11.3.3 - Vertical and Horizontal Emplacement Orientation Decision

A system study (CRWMS M&O, 1994d) was concluded during this reporting period. This study evaluated several different emplacement modes. The emplacement modes considered were large waste packages (12 pressurized-water reactor and 21 pressurized-water reactor) emplaced in-drift, either center-in-drift or off-center-in-drift, and in short perpendicular alcoves along the drift. In addition, smaller waste packages (9 pressurized-water reactor) emplaced in vertical boreholes were considered. These concepts are described in detail by Bhattacharyya (1994). The emplacement mode study considered preclosure health and safety, and cost, in comparing each emplacement mode. The center-in-drift mode was found to be the most cost-effective of the emplacement modes considered. The vertical borehole mode did provide greater preclosure safety; however, the reduced waste package size and the need to provide the waste package basket (since the larger multi-purpose canisters could not be used) resulted in high costs for this emplacement mode. In addition, many of the safety risks associated with the center-in-drift emplacement mode can be reduced as the design progresses, thus reducing the difference in safety between the options.

At this time, the impact of the emplacement mode on postclosure performance has not been evaluated in detail. To evaluate the impact of the emplacement mode on postclosure performance, the details of water movement in the vicinity of the emplacement drift must be better understood. This understanding will be achieved throughout site characterization and early operations of the repository.

Forecast: Development of the horizontal in-drift emplacement mode is expected to continue through the sequence of design phases.

4.1.9 Design Activity 1.11.3.4 - Drainage and Moisture Control Plan

The objective of this activity is to provide postclosure design requirements for the layout of the underground facility. The requirements are to limit the amount of water in contact with the container to provide a favorable containment and isolation environment.

Current work under this activity is closely related to that in Section 4.1.16 and to a lesser extent in Section 4.1.8. The current thermal loading strategy is to develop a layout to accommodate a high thermal load and an alternative low thermal load. Repository layouts being developed are considering combinations of waste package and emplacement drift spacing for the assumed thermal loading strategy. Specific thermal studies of rock temperatures resulting from these various layouts have not been made, but some results discussed in Section 4.1.16 are applicable. The requirements to be developed are dependent on the thermal loading that will be adopted: an extended high thermal load, or a minimum thermal disturbance (low thermal load). For example, there may be no concern over postclosure drainage for an extended high thermal load, but there may be much concern over postclosure drainage for a low thermal load.

Current repository layouts provide for the entire repository emplacement level to drain to a low point at the northeast end. The emplacement drifts themselves are sloped so no ponding will occur in them. The layout of the Exploratory Studies Facility uses the results of the performance assessment analyses discussed in Section 4.1.13 and provides for drainage to a sump, with subsequent water removal.

As Advanced Conceptual Repository design proceeds, options for controlling moisture movement will be evaluated as part of the alternatives for improving repository performance.

Forecast: In FY 1995 work will continue to further refine and expand this design. Investigation will begin of rock temperatures resulting from the various drift and waste package spacings being considered.

4.1.10 Design Activity 1.11.3.5 - Criteria for Contingency Plan

Although not specific to this activity, the changes to the underground repository layout described in Section 4.1 address the concerns originally raised in this section. Work toward a

contingency plan has been done in two areas: defining a volume of rock suitable for a repository and locations of excavations relative to faults. The former is discussed in Section 4.1.7, and the latter is discussed below.

Repository openings will be located, to the extent practical, to avoid faults that traverse a major portion of the potential emplacement area. Avoidance is assumed to be adequate at this stage of design by using a 60-m offset from the main trace of a fault at the repository level. An exception to this is that a 120-m offset will be used on the west side of the Ghost Dance fault because the Exploratory Studies Facility Topopah Spring main drift will be excavated before the Ghost Dance fault characteristics are fully investigated. Where avoidance cannot be achieved, a 15-m standoff of emplaced waste packages from the edges of Type 1 fault zones that intersect emplacement drifts will be used.

Forecast: Work in FY 1995 will study ground support systems for ranges of ground parameters. In conjunction with Section 4.1.7, consideration will also be given to ground conditions in which emplacement should not occur, and in the extreme, ground conditions through which excavation should be avoided if possible. The need for contingency planning to accommodate unexpected conditions will be considered throughout repository Advanced Conceptual Design.

4.1.11 Design Activity 1.11.4.1 - Chemical Changes Resulting From the Use of Construction Materials

Related work is discussed under the appropriate activities of Chapter 5, Section 5.2.2, Characterize Chemical and Mineralogical Changes in the Postemplacement Environment, and Chapter 5, Section 5.2.6., Characterize the Effects of Man-Made Materials on Water Chemistry in the Postemplacement Environment.

Forecast: The related activity discussed in Chapter 5, Section 5.2.6, will continue the study of the effects of diesel exhaust in the Exploratory Studies Facility.

4.1.12 Design Activity 1.11.4.2 - Material Inventory Criteria

Through the Determination of Importance Evaluations described in Section 2.3.2, controls are placed on the use of tracers, fluids, and materials during construction and testing. All materials used underground are to be documented. A data base containing both planned and actual usage is maintained by EG&G. This documentation is a lifetime Project record.

Efforts in this activity have been concentrated on establishing controls (i.e., limitations) on use of materials in the Exploratory Studies Facility, specifically at the North Ramp. All materials proposed for use are evaluated for potential effects on waste isolation and appropriate controls established. If an evaluation is inconclusive, the use of the material is temporarily forbidden or a conservative approach to its use is taken. This evaluation process will be an ongoing effort as the Exploratory Studies Facility Design Packages are developed.

The evaluations and controls will apply to repository design as well. The following are examples of controls that have been imposed to date:

- Tunnel boring machine operation and maintenance to prevent or control oil loss
- Restricted and prohibited use of cement grouting in test alcoves
- Minimizing use of permanently retained organics to the extent practicable
- Mitigating leakage of organics from equipment as soon as practical
- Use of diesel underground (currently there is a hold on its use)
- Use of chlorides in ground enhancing materials, concrete, and grout
- Chemical grout injections to stabilize weak ground.

Forecast: Evaluation of effects of materials on waste isolation and establishing controls will continue throughout FY 1995. A Project-level procedure is also planned to be issued in the next reporting period; this procedure will provide guidance to participants in the implementation of the Tracers, Fluids, and Materials Management Plan (DOE, 1994e).

4.1.13 Design Activity 1.11.4.3 - Water Management Criteria

Calculations were performed to evaluate the sensitivity of hydrological performance assessment analyses of the potential impact on waste isolation of the following parameters:

- Sensitivity of evaluation of water movement to characterization of PTn hydraulic parameters
- Sensitivity of evaluation of water movement to heterogeneity of material properties
- Sensitivity of evaluation of water movement to fracture/matrix characterization
- Sensitivity of evaluation of underground water movement to modeling of rock drying effects due to ventilation.

An analysis was also done to assess the effect of this sensitivity on the recommendations provided by previous performance assessment analyses.

The results of the calculations were evaluated for their potential impact on Exploratory Studies Facility design, construction, and operations. Conclusions drawn from the calculations were compared to those drawn from Exploratory Studies Facility Performance Assessment Analysis 3 (Sobolik and Fewell, 1992), Analysis 12 (Sobolik and Fewell, 1993), and Analysis 13 (Dunn and Sobolik, 1993).

The analyses indicated that pooled water on the tunnel floor will continue to infiltrate the rock as long as the two are in contact. Furthermore, the sensitivity studies indicate a connected fracture system with apertures of 25 μm or greater in the Topopah Spring section of the tunnel could create a preferential pathway for water flow to the Calico Hills units that could impact waste isolation capabilities.

For these reasons, during construction and operation of the Exploratory Studies Facility, excess water should be removed to preclude adding unnecessary water to the Exploratory Studies Facility tunnel wall rock. Water should not be allowed to puddle, pond, or stand on the floors of the tunnels, and it is suggested that a readily-available water pickup system be accessible to immediately pick up any standing water which may collect during the construction or operation phase of the Exploratory Studies Facility.

Forecast: No activity is planned for FY 1995.

4.1.14 Design Activity 1.11.5.1 - Excavation Methods Criteria

The objective of this design activity is to identify any constraints to be placed on excavation because of postclosure performance considerations. The concern is to limit excavation-induced changes to rock mass permeability.

Progress Report #10 stated that it is generally accepted that use of a tunnel boring machine results in the least amount of change due to the excavation process. Properly controlled drill-and-blast excavation may result in damage equivalent to that from a tunnel boring machine, but any lesser control will result in greater change. A revised repository layout is being developed which allows most of the excavation to be performed by tunnel boring machine. All repository layout options being considered have as a goal the maximum use of two tunnel boring machines. It is also a desire to perform all other excavation by other mechanical means. Equipment research and development by the Colorado School of Mines (under a Project contract) may offer the flexibility necessary to mechanically excavate noncircular profiles (e.g., for alcoves or support facilities) and to excavate in locations not readily accessible by a tunnel boring machine. It is assumed that this equipment will be fully developed and tested and will be available for repository construction, thereby eliminating the need to utilize drill-and-blast techniques to perform secondary excavation tasks.

Based on the above discussion, Progress Report #10 reported the conclusion that constraints need be placed only on drill-and-blast excavation, and that because the design now assumes the majority of the repository excavation will be done using a tunnel boring machine and the remainder using other mechanical methods, blasting constraints are unnecessary.

Forecast: Tracking of progress in equipment development by the Colorado School of Mines will continue throughout FY 1995. Blasting constraints will be developed only if further Advanced Conceptual Design studies indicate significant excavation by blasting will be required for repository development.

4.1.15 Design Activity 1.11.5.2 - Long-Term Subsidence Control Strategy

The Site Characterization Plan states that there are two major concerns over long-term subsidence: the potential for postclosure ground surface subsidence and the potential for any postclosure ground movement (not necessarily sufficient to reach ground surface) to affect the

waste isolation capabilities of the site. Ground surface subsidence is usually caused by collapse or failure of the pillar. Other ground movement can be caused by collapse or failure of the drift roof.

The approaches proposed by the Site Characterization Plan to deal with these concerns are to limit the excavation extraction ratio and drift size and to place backfill in the drifts prior to closure and decommissioning. Current repository layouts are based on a conservative excavation extraction ratio of 30 percent within the waste emplacement areas. This value corresponds to a drift spacing such that parallel drifts are barely subjected to the stress effects of adjacent drifts, which limits the stress in the pillars. Drift size will be governed by the development and operations needs; the range in drift sizes being considered is not expected to vary significantly. Minor variations in drift size will not affect the pillar stress if the extraction ratio remains constant. Preliminary calculations performed to date indicate this low extraction ratio will result in relatively low pillar stress levels. These stress levels make it very unlikely that ground subsidence will be caused by pillar failure.

The current project assumption is that there will be no backfill in the emplacement drifts (CRWMS M&O, 1994b). To date, no performance requirements have been allocated to the backfill, and presence of backfill may raise the waste package temperatures. No analyses have been made of potential rock movement caused by roof instability, with or without backfill in place.

Forecast: Subsidence mechanisms and roof stability will be studied as part of thermomechanical studies to be performed during FY 1995.

4.1.16 Design Activity 1.11.6.1 - Thermal Loading for Underground Facility

An update of the findings of the systems study to date was published (CRWMS M&O, 1994e). A summary of the findings of the report follows.

Types of measurements and associated instruments required to conduct a performance confirmation program were identified. The FY 1993 thermal loading study reported that since electronic components exhibit high failure rates above 160°C, temperatures above this value should be avoided. However, a survey of instruments for monitoring waste packages, the drift environment, and near-field rock characteristics conducted in support of the FY 1994 thermal loading study showed that measurements of rock characteristics could be made in environments of up to 200°C. Therefore, the thermal goal for drift wall temperatures can probably be set to as much as 200°C. Thermomechanical calculations were also performed to evaluate drift stability characteristics associated with elevated temperatures. The analysis found that the stresses produced in the rock at thermal loads of 27.4 kgU/m^2 (111 MTU/acre) would exceed the current stability criteria and, therefore, some sort of ground support would be required. These were preliminary analyses and need to be followed up with more detail. It should be noted that ground support is currently included in the preliminary repository Advanced Conceptual Design concepts.

A number of sensitivity analyses were initiated. In three instances they were sufficiently complete to provide a recommendation for testing of a particular parameter. Specifically, the investigation of bulk permeability started in the FY 1993 study was completed. Currently the bulk permeability in the TSw2 unit has significant uncertainty (values extend over two orders of magnitude from 10^{-13} to 10^{-11} m^2 [0.1 to about 10 Darcy]) based on very limited borehole measurements. The equivalent continuum model analyses showed that a knowledge of bulk permeability is important to predicting water movement in Yucca Mountain and for selecting a thermal loading. The calculations showed a significant increase in gas-phase convection if bulk permeabilities are in the range of 1 to 10 x 10^{-12} m^2 (1 to 10 Darcy). Thus, a better understanding of this parameter is necessary to appropriately estimate water movement.

Calculations were initiated to determine the amount of local boiling that will occur, particularly with the large waste packages at low thermal loads, and the amount of dryout experienced on a drift-scale. Preliminary results determined that the amount of dryout is critically dependent on the diffusive gas flux that occurs. It was found that a nominal value for the diffusive gas flux produced little dryout around the drift. However, when a much higher value was used (due to the fact that the soils literature to some extent supports a higher diffusion enhancement factor) a significant dryout region was created. The uncertainty range of this parameter is currently about two orders of magnitude in Yucca Mountain which results in uncertainty in Performance Assessment calculations.

At different locations in the primary area and alternate areas of the potential repository, the depths from the repository to important stratigraphic units in Yucca Mountain vary significantly. Sensitivity analyses were performed in which the effects of varying the depth on thermohydrologic performance were examined. The calculations showed that depending on thermal loading, changes in depth were important in predicting temperatures as well as in determining the amount of water buildup above the repository horizon. Specifically, the analysis found that going from an overburden of 200 to 430 m resulted in nearly tripling the time at which a portion of the potential repository stays above a certain temperature (such as 50°C) for the thermal loads that produce bulk average above-boiling conditions (bulk average above 97°C).

Numerical simulations were performed in conjunction with nonisothermal flow experiments (see Chapter 6, Section 6.5.2, Subactivity 1.6.2.2.2) to better understand the mechanisms associated with nonisothermal flow. Nonisothermal behavior is critical to the Project's ability to predict temperature and moisture distributions within Yucca Mountain. Simulations were performed for partially saturated media and fields of varying permeability. Numerical results were documented and indicated that the next step in the Project's nonisothermal investigations should focus on representative tuffaceous materials (Ho and Eaton, in prep.).

The impact of thermal property heterogeneity was investigated by examining the effects of thermal property representations on predicted temperature profiles. Models developed for this investigation include single material, uniform layered material, dipping layered material, and geostatistical realizations of property distributions. Evaluations of the results show that

both the resolution of geologic structure and the thermal property representations can have a noticeable effect on predicted far-field temperatures (Logenbaugh et al., in prep.). More importantly, a method for linking geostatistical simulations with finite element models was developed that appears promising for extensions of this work into three dimensions.

Results from near-field thermal analyses completed for the FY 1993 Thermal Loading Systems Study were documented (Ryder and Holland, 1994) and transmitted to the M&O. Output files were also transmitted to the M&O for use in their mechanical evaluations. In addition, analyses were initiated to evaluate the impacts of variations in waste package characteristics (i.e., power output, burnup, and age) within a given year's emplacement inventory on predicted host-rock thermal response. Results should be available early in the next fiscal year.

Forecast: Thermal and mechanical analyses will be provided in support of the systems studies. Specific scopes of work and analysis definitions will be negotiated at the beginning of the fiscal year.

4.1.17 Design Activity 1.11.6.2 - Borehole Spacing Strategy

With the change to in-drift emplacement by the Project (CRWMS M&O, 1994b), boreholes are no longer being used for waste emplacement. Waste packages are now being emplaced in drifts, so the activity is now concerned with the emplacement drift spacing strategy. The spacing strategy is currently being addressed and initial results are summarized below. They are described in more detail in CRWMS M&O (1994a).

Emplacement drift spacing cannot be considered independently of waste package spacing in the emplacement drifts. Both are functions of thermal loading. For a given thermal loading, waste package and emplacement drift spacing are inversely related. A small waste package spacing and a large emplacement drift spacing will produce the same thermal loading as a large waste package spacing and small emplacement drift spacing. However, these equivalent thermal loadings may not produce the same temperatures on the surface of the waste package and in the rock mass.

Thermal loading is commonly expressed in two ways: areal power density, which has units of energy per area such as kW/acre; and areal mass loading, which has units of mass per area such as MTU/acre. Thermal output of a waste package at any time is a function of enrichment, age, and burnup, and is expressed in kilowatts. Many combinations of these three variables may result in the same instantaneous waste package thermal output, but each will have a different thermal decay curve. Using areal power density as a basis for spacing, all waste packages with the same thermal output at time of emplacement will have the same spacing. However, if they have different thermal decay curves, the temperature distribution in the repository may vary significantly with time. Using areal mass loading, the MTU in a waste package does not vary with time. Waste packages with the same MTU may have radically different thermal outputs and decay curves. Therefore, spacings based on areal mass

loading may result in near-field temperature goals being exceeded because the effect of different thermal decay curves are not considered.

Because of the potential problems associated with basing spacings on areal power density and areal mass loading, another thermal loading approach is being considered. This approach, called the equivalent energy density, uses the total energy produced by a waste package over some period of time (such as 1000 years) as the guideline from which spacings can be derived.

The following are several general observations regarding an emplacement drift spacing strategy:

1. One key to accommodating higher loadings is to maintain a close enough emplacement drift spacing so that geometric considerations such as package length do not limit the loading to a value lower than what might otherwise be desirable. It is not suggested that emplacement drift spacing be set so close that the openings and pillars might be regarded as potentially unstable, but that the closest spacing judged to be stable over the long term be given ample consideration. Other factors being equal, the more closely spaced drifts permit emplacement of higher initial heat output packages because package spacings inside the drift increase with decreasing drift spacing. This may be an important factor in determining the maximum initial heat output package that can be accommodated.

2. It is both unnecessary and impractical to vary emplacement drift spacing to achieve a particular thermal loading strategy. To do so will limit flexibility with regard to potential changes that might be considered during operations such as repositioning of packages to facilitate extended dryout or other thermal management decisions.

3. To ensure wide enough spacings for the higher thermal energy packages and to permit close enough spacings for cooler packages that might otherwise be limited by their physical length (for in-drift emplacement), the preferred method is to intermingle packages of different waste types, quantities, and thermal characteristics in the emplacement drifts. A sizeable lag storage facility may be required, but the blending thus facilitated will tend to reduce the average package spacing, resulting in lower development costs (less emplacement drift required per package), while helping to establish a more uniform thermal environment across the repository (CRWMS M&O, 1994e).

Forecast: Work will continue in FY 1995 to further define the emplacement drift strategy, including use of the equivalent energy density approach.

4.1.18 Design Activity 1.11.6.3 - Sensitivity Studies

These studies were continued during the repository period. The thermal loading system study reported a performance evaluation sensitivity to bulk permeability in TSw2 unit, diffusive gas flux, and the repository depth. These sensitivities are discussed further in Chapter 4, Section 4.1.16.

Forecast: The FY 1995 thermal loading effort will concentrate on identifying site-related parameters which impact performance assessments.

4.1.19 Design Activity 1.11.6.4 - Strategy for Containment Enhancement

The Site Characterization Plan approach to containment enhancement under this activity is to control the post-emplacement environment within the repository, specifically by achieving uniform temperature across the repository by varying waste package spacing. Work on this activity was indirect in that waste package spacing is related to emplacement drift spacing, as discussed in Chapter 4, Section 4.1.17. Progress in the effects of various environments on the waste packages and containment are described in Chapter 5, Sections 5.2.1 and 5.2.2. Progress in claiming additional credit for containment is described in Chapter 5, Sections 5.1.5 and 5.3.8.

Forecast: Studies of containment enhancement by means of varying the waste package spacing for high and low thermal loadings will be conducted during the next reporting period. This is part of a larger study of waste emplacement management which is intended to evaluate methods of enhancing waste containment and repository performance. It will also consider such elements as waste acceptance strategies, waste aging, waste package placement sequence, waste package relocation subsequent to initial emplacement, and drift ventilation following emplacement. A report of the study will be issued in March 1995.

4.1.20 Design Activity 1.11.6.5 - Reference Calculations

The objective of this design activity is to provide a set of calculations, documenting predictions of postclosure thermal and thermomechanical response of the host rock, which may be used to address performance assessment issues. Thermal and thermomechanical response analyses performed to satisfy this design activity can be divided into near-field and far-field analyses; the near-field analyses can be further divided into container scale analyses and drift scale analyses.

Container scale deals with rock behavior in the immediate vicinity of the waste package and its effect on the waste package. This portion of the analysis as originally intended was focused on the stability of the boreholes in which the waste packages were to be placed. However, with a change to in-drift emplacement by the Project (CRWMS M&O, 1994b), borehole stability is no longer a concern. The canister scale analysis will now focus on effects of backfill on waste packages. Preliminary studies performed to date indicate that

presence of backfill around a waste package tends to raise the waste package temperature. This is because most backfills have low thermal conductivities and tend to act as an insulator. Preliminary studies also indicate that with a proper zoning of backfill gradations (e.g., a fine graded backfill placed over a coarse graded backfill that is in contact with the waste package) will keep water from contacting the waste package for unsaturated flow conditions. However, placing such a zoned backfill with consistency is very difficult.

With the change to in-drift waste package emplacement, drift scale analyses, to the extent that backfill is considered, overlap some with the container scale analyses. This analysis deals with postclosure behavior of the rock in the immediate vicinity of the emplacement drift and the potential for that rock to move or collapse and develop new paths for radionuclides to reach the accessible environment. Some preliminary studies performed by SNL in recent years have dealt with postclosure stability of the drifts for different thermal loadings. These studies have not indicated any rock stability problems that would affect waste isolation. An aspect of rock stability mentioned in the Site Characterization Plan is to backfill the drifts to minimize the amount of rock that can collapse or loosen. Backfill also was to provide protection for the waste packages against damage from rock falls. As previously mentioned in Section 4.1.15, the Project has made the assumption that emplacement drifts will not be backfilled (CRWMS M&O, 1994b).

Far-field analyses deal with the far-field performance of the repository. For the most part, this involves thermal response of the rock mass and the effect of temperature on rock joints. Studies by LLNL regarding temperature distribution in the rock as caused by various repository thermal loads is relevant to this activity. Scoping studies performed for the Total System Performance Assessment are also relevant.

Forecast: Near-field thermal and thermomechanical studies of drift temperature and stability will be conducted throughout FY 1995.

4.1.21 Design Activity 1.11.7.1 - Reference Postclosure Repository Design

In the previous Progress Report the focused Advanced Conceptual Design approach was discussed. During the current reporting period, Advanced Conceptual Design for the repository continued with the "focused" Advanced Conceptual Design approach being fully implemented. In addition, during this period, two documents regarding the reference Postclosure Repository Design were published. The first document (CRWMS M&O, 1994b) contains a compilation of assumptions related to requirements, technical data, and design concepts which were necessary to facilitate the design process. The document also contains a list of repository/waste package functions and a first draft of a repository operations concept. The second document (CRWMS M&O, 1994a) contains a summary of the waste package and repository design concepts as they currently exist. The waste package design is nearing the end of Advanced Conceptual Design and the repository is in the very early stages of Advanced Conceptual Design. As the designs progress they will be documented in the Interim Advanced Conceptual Design Summary Report followed by the Final Advanced Conceptual Design Summary Report.

Forecast: The design effort will continue with a focus on horizontal in-drift emplacement of large waste packages.

4.1.22 Design Activity 1.11.7.2 - Documentation of Compliance

No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

4.2 REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY (SCP SECTION 8.3.2.3)

Radon levels in the Exploratory Studies Facility are measured for reasons of regulatory compliance and worker safety. Knowledge of radon levels in the Exploratory Studies Facility can be used to forecast possible radon exposure in a future operating repository. A monitoring protocol was established in April 1994.

Forecast: Monitoring is scheduled at quarterly intervals in FY 1995, beginning in November 1994. Future measurements will depend upon the status of the Exploratory Studies Facility construction and radiological safety factors at that time.

4.2.1 Design Activity 2.7.1.1 - Design Evaluation for Compliance with Radiological Safety Design Criteria and Performance Goals

Knowledge of radon levels in the repository are measured for worker safety reasons and for environmental impact assessments; they can be used to forecast possible radon exposure from the operating repository. Measurement of radon concentrations in the repository drift began in April 1994.

Forecast: The sampling regimen is scheduled to continue at quarterly intervals during FY 1995. An initial evaluation of radiological safety issues will be performed during FY 1995.

4.3 NONRADIOLOGICAL HEALTH AND SAFETY (SCP SECTION 8.3.2.4)

4.3.1 Design Activity 8.3.2.4.1.1 - Design Activity to Verify Access and Drift Usability

A second set of analyses of the 2C section of the North Ramp was completed and transmitted to YMSCO. The analyses examined the impacts of in situ, thermal, and seismic loading on the stability of the North Ramp. In addition, large-scale body effects were identified that may have performance assessment implications. Specifically, large zones of

tension and compression were predicted that may impact hydrologic flow paths. These results are currently being evaluated.

Forecast: Subject to FY 1995 funding allocations, a strategy and planning document for development of the scientific basis for design will be developed. The document will outline a basis strategy, identify specific activities that contribute to development of the scientific basis for design, and show how these activities should be phased with the repository design activities needed to support a recommendation for Technical Site Suitability and for License Application.

Several design assumptions identified in the Controlled Design Assumptions Document will be substantiated through the consolidation of existing data and through making data readily accessible to Project participants. Specific areas that will be substantiated include those of rock mass thermal expansion coefficient, rock mass quality indices, and rock mass deformation moduli. Activities will focus on the substantiation needs concerning mechanical data in the technical data section of the Controlled Design Assumptions Document.

4.3.2 Design Activity 8.3.2.4.1.2 - Design Activity to Verify Air Quality and Ventilation

No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

4.4 PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY (SCP SECTION 8.3.2.5)

4.4.1 Design Activity 4.4.3.1 - Operations Plan to Accompany the Advanced Conceptual Design

A draft Concept of Operations for the Mined Geologic Disposal System has been written as Chapter 5 in the Controlled Design Assumptions Document (CRWMS M&O, 1994b). The Concept of Operations covers the period beginning with receipt of waste at the Mined Geologic Disposal System through establishment of postclosure institutional barriers. It describes, at a level of detail appropriate to Advanced Conceptual Design, all Mined Geologic Disposal System operations in the following major categories: waste handling, subsurface development, system performance evaluation, Mined Geologic Disposal System support operations, and permanent closure. Some of the operational concepts are listed in the Controlled Design Assumptions Document as assumptions to be substantiated during Advanced Conceptual Design.

Forecast: The Concept of Operations will be updated as the Advanced Conceptual Design is further developed during FY 1995.

4.4.2 Design Activity 4.4.3.2 - Operations Plan to Accompany the License Application Design

No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

4.4.3 Design Activity 4.4.4.1 - Repository Design Requirements for License Application Design

No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

4.5 SEAL CHARACTERISTICS (SCP SECTION 8.3.3.2)

4.5.1 Study 1.12.2.1 - Seal Material Properties Development

Activities 1.12.2.1.1 and 1.12.2.1.2. No progress during the reporting period; these were unfunded activities.

Forecast: Subject to FY 1995 funding allocations, Study Plan 8.3.3.2.2.1 (Seal Materials Properties Development) will be completed and submitted to YMSCO at the end of FY 1995. The study plan will describe the laboratory experiments necessary to establish the thermomechanical and hydrologic properties of candidate sealing materials including cements, clays, and crushed tuff. Tests that assess the longevity and geochemical stability of the candidate sealing materials will also be described.

Laboratory sealing tests will also be conducted. These tests are intended to assist in the rational development of future large-scale sealing tests, borehole sealing tests, and seal system designs. These tests will be conducted on various candidate sealing materials under controlled conditions to aid in the understanding of the performance of similar configurations emplaced in situ tests.

4.5.2 Design Activity 1.12.2.2 - A Degradation Model for Cementitious Materials Emplaced in a Tuffaceous Environment

No progress during the reporting period; this is an out-year activity.

Forecast: No activity is planned for FY 1995.

4.5.3 Study 1.12.2.3 - In Situ Testing of Seal Components

Study Plan 8.3.3.2.2.3, "In Situ Testing of Seal Components," was submitted to YMSCO for review on September 7, 1994. This study plan describes the in situ experiments necessary to verify seal designs and design concepts. The experiments focus initially on small-scale experiments that evaluate materials, emplacement concepts, and emplacement techniques. Subsequent experiments will apply the results of the small-scale tests toward larger performance confirmation tests.

Laboratory tests were initiated on Portland and gypsum-based cements. These tests included mineralogic, petrologic, and geochemical analyses of the Y-7 gypsum cement intended to be used in the Vertical Seismic Profiling testing in the unsaturated zone boreholes at Yucca Mountain. This cement is intended to be used as a coupling agent for downhole geophones. Also, realistic laboratory tests to evaluate the performance of candidate sealing materials recommended by Fernandez et al. (1994) were initiated. These tests include characterization of the mechanical and fluid properties of candidate sealing materials as well as actual emplacement and permeability testing in laboratory samples of tuff. These tests are designed after similar tests conducted by Akgun and Daemen (1989) and South and Daemen (1986) for NRC. This preliminary laboratory testing will be used to define experiments for the completion of Study Plan 8.3.3.2.2.1, "Seal Materials Properties Development," and to provide baseline data for the in situ experiments to be conducted under Site Characterization Plan Study 8.3.3.2.2.3, "In Situ Testing of Seal Components." The results of all laboratory testing during FY 1994 are documented in the annual report on seal testing (Finley et al., in prep.[a]).

Forecast: Subject to FY 1995 funding allocations, laboratory testing will continue on various cementitious and earthen seal materials. The results of these lab tests will provide data and information to support the Advanced Conceptual Design and in situ experiments aimed at evaluating and verifying seal design and emplacement concepts. The laboratory testing will also support the abandonment requirements for site characterization boreholes at Yucca Mountain.

4.5.4 Design Activity 1.12.4.1 - Development of the Advanced Conceptual Design for Sealing

Design Subactivity 1.12.4.1.1 - Define subsystem design requirements. A sealing and backfilling strategy was developed for the Exploratory Studies Facility/Repository openings. The strategy is to minimize water contact with the waste package by diversion, enhanced infiltration, and structural stability of the host rock by the use of engineered backfills. A report outlining the strategy attempts to demonstrate isolation of water from all sources entering shafts/ramps or the underground from the waste packages by infiltration and diversion (Finley et al., in prep.[b]). Sealing concepts based on the current proposed design concepts are also included, as well as a description of sealing issues, some of which may be impacted by the current "in-drift" emplacement concepts being proposed.

Design Subactivity 1.12.4.1.2 - Perform trade-off studies to support advanced design development. No progress during the reporting period. The emphasis during the reporting period was in support of Design Subactivity 1.12.4.1.1.

Forecast: Subject to FY 1995 funding allocations, the objectives for FY 1995 are to conduct activities that will support and/or substantiate the repository Advanced Conceptual Design in the area of sealing shafts, ramps, and underground facilities and evaluate sealing requirements and assumptions for Advanced Conceptual Design. In addition, site information necessary for the development of preliminary designs for North Ramp seals will be collected and evaluated. This site data is necessary to evaluate the coupled response of the seal/rock system that will likely occur at prospective seal locations.

Design Subactivity 1.12.4.1.3 - Develop advanced conceptual design for seals. No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

4.5.5 Design Activity 1.12.4.2 - Development of the License Application Design for Sealing

Design Subactivities 1.12.4.2.1 through 1.12.4.2.3. No progress during the reporting period. These are out-year activities.

Forecast: No activity is planned for FY 1995.

CHAPTER 5 - WASTE PACKAGE

The waste package consists of the waste form (spent nuclear fuel or high-level waste glass), possibly a multi-purpose canister, and a disposal container. The waste package program includes the development of waste package design bases, design analysis, container materials testing, development of a reference design, waste form testing, and characterization of the waste package emplacement environment. Progress in the waste package program is described in this section.

5.1 WASTE PACKAGE DESIGN (SCP SECTION 8.3.4.2)

5.1.1 Design Activity 1.10.2.1 - Concept Development

The multi-purpose canister is a triple purpose, sealed, metallic container that is used for storing, transporting, and disposing of spent nuclear fuel assemblies. Multi-purpose canisters have a single shell with inner and outer lids that are welded to provide a dry, inert environment for the spent nuclear fuel (see Figure 5-1). Each multi-purpose canister is contained within an additional package designed uniquely for the system functions of storage, transportation, and geologic disposal. Conceptual design of the multi-purpose canister is based on existing technology adapted to the specific requirements of the multipurpose environment. Two sizes of multi-purpose canisters are provided: a large, nominally 125-ton multi-purpose canister, and a small, nominally 75-ton multi-purpose canister.

The multi-purpose canister must satisfy requirements for structural strength, heat transport, criticality safety, and radiation shielding. To provide for its various phases of use, the multi-purpose canister is being designed in accordance with 10 CFR Part 71 for spent nuclear fuel transportation, 10 CFR Part 72 for spent nuclear fuel storage, and 10 CFR Part 60 for spent nuclear fuel disposal. Though sufficient information is not yet available to seek licensing of the multi-purpose canister for permanent disposal, design features incorporate current licensing criteria for the disposal phase. This is accomplished by incorporating known repository design requirements into the multi-purpose canister design.

In September 1994, DOE published a document (DOE, 1994y) summarizing DOE efforts to investigate various container systems for handling, transporting, storing, and disposing of spent nuclear fuel assemblies. The primary goal of the DOE investigations was to select a container technology that could handle the vast majority of commercial spent nuclear fuel at a reasonable cost, while ensuring the safety of the public and protecting the environment. Several alternative cask and canister concepts were evaluated for spent nuclear fuel assembly packaging to determine the most suitable concept. Of these alternatives, the multi-purpose canister system was determined to be the most suitable.

Concept development has focused on screening of design concepts and improved characterization of the design basis fuel. Activities in this area are discussed below.

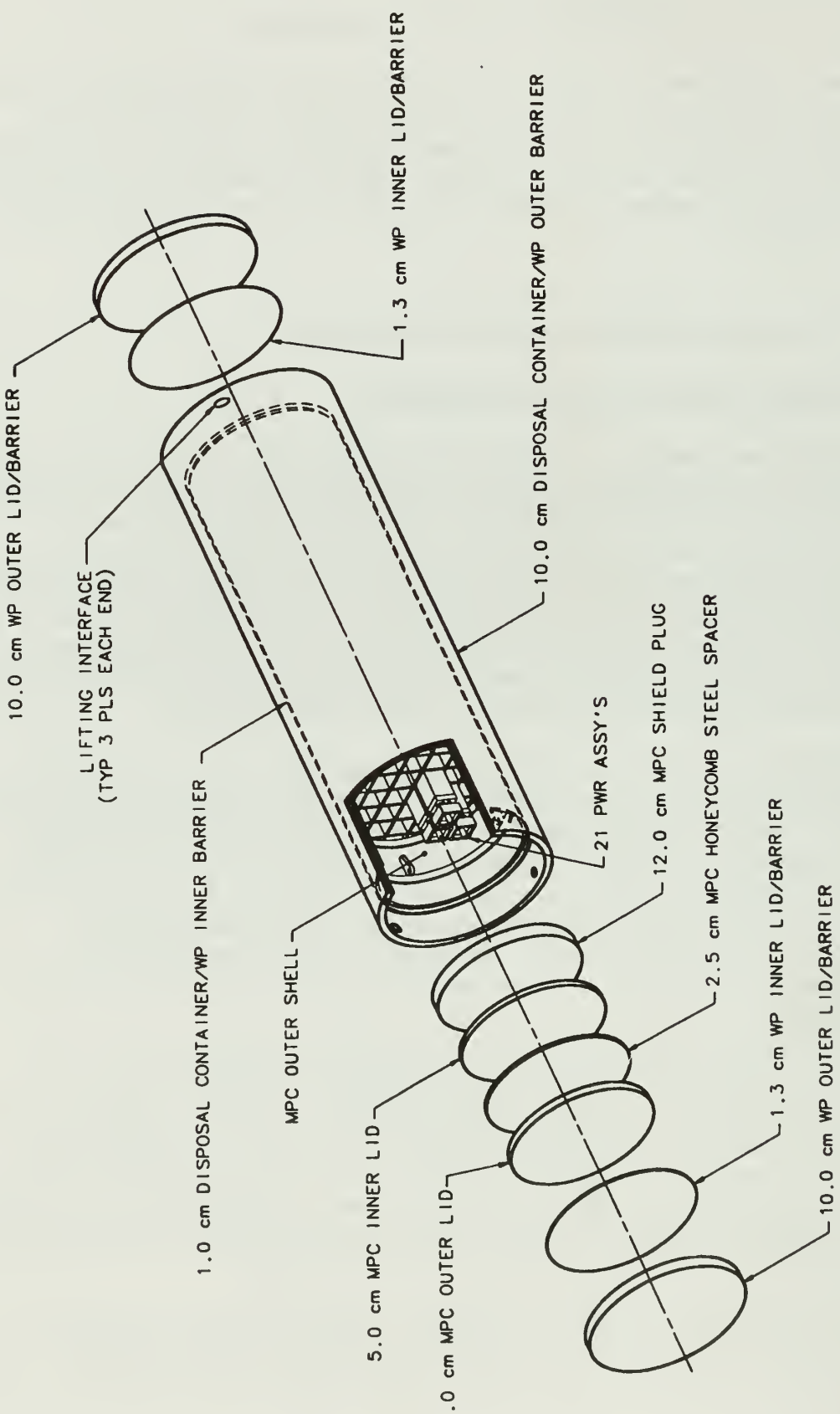

10.0 cm WP OUTER LID/BARRIER
LIFTING INTERFACE
(TYP 3 PLS EACH END)
1.0 cm DISPOSAL CONTAINER/WP INNER BARRIER
MPC OUTER SHELL
5.0 cm MPC INNER LID
7.0 cm MPC OUTER LID
1.3 cm WP INNER LID/BARRIER
10.0 cm DISPOSAL CONTAINER/WP OUTER BARRIER
21 PWR ASSY'S
12.0 cm MPC SHIELD PLUG
2.5 cm MPC HONEYCOMB STEEL SPACER
1.3 cm WP INNER LID/BARRIER
10.0 cm WP OUTER LID/BARRIER

Figure 5-1. Multi-Purpose Canister (with Disposal Overpack)

Activity 1.10.2.1.1 - Advanced Conceptual Design concepts. From the various proposed conceptual designs, three have been chosen for further development. All are metallic, multibarrier disposal containers, and each has a total wall thickness that is sufficient to control radiolytic effects. The three are not alternatives; instead, the different designs are to accommodate different types of waste. The concepts are:

- Disposal container for multi-purpose canister
- Disposal container for uncanistered fuel
- Disposal container for defense high-level waste.

Disposal containers for multi-purpose canisters will have a capacity of one multi-purpose canister. The disposal container provides long-term containment, mechanical protection, and handling features. The multi-purpose canister is a metallic container for storing and transporting spent nuclear fuel assemblies, and it is expected to be compatible with disposal requirements. There are two sizes of multi-purpose canister to accommodate differences in utility loading capabilities. In September 1994, DOE published a document (DOE, 1994y), in which several alternative cask and canister concepts are evaluated. Of these alternatives, the multi-purpose canister system was determined to be the most suitable.

Disposal containers for uncanistered fuel will contain baskets to provide mechanical support, control criticality, and promote conduction of heat to the shell. In addition, angle-iron guides and other structural forms are installed in the waste package to provide basket structural support and to guide installation of the basket. These are currently to be of the same corrosion resistant material as the inner barrier.

Disposal containers for defense high-level waste will have a capacity of four glass waste canisters. Locating devices will be provided to facilitate loading of the waste canisters into the disposal container.

Activity 1.10.2.1.2 - Design basis fuel. Previous analyses of the fuel to be delivered to the repository have been extended to consider age explicitly for two waste receipt scenarios: oldest fuel first and youngest fuel first with 10-year minimum age. The analysis was done for pressurized-water reactor and boiling water reactor fuel separately, but because boiling water reactor fuel has a much lower heat output and criticality potential, the selection of design basis fuel depended primarily on projected pressurized-water reactor fuel deliveries.

The selection of a waste package design basis fuel is based on two considerations: the most robust design which can be practically produced, and the percentage of the fuel which such a design can accommodate without de-rating. Preliminary analyses have been performed to determine the thermal load and fuel reactivity that can be handled by the conceptual designs. The fraction of fuel that can be accommodated by the conceptual designs without de-rating was also determined.

Heat outputs for a waste package with 21 pressurized water reactor assemblies were calculated for various combinations of waste receipt scenarios and inventory assumptions (the

full 86 x 10^6 kg U to be discharged and fuel to be discharged before year 2003). Heat outputs for various percentiles of the fuel were calculated.

Forecast: Corrosion testing of container materials identified at the waste package workshop will begin. Development of design basis fuel will continue.

Structural analyses of the basket support hardware will be performed. The permissibility of changing the structural support material to lower-cost austenitic stainless steel will be determined.

5.1.2 Design Activity 1.10.2.2 - Design Tools

The design and analysis programs that were verified and validated during the previous reporting period are still in use. No additional software has been verified and validated.

5.1.3 Design Activity 1.10.2.3 - Design Evaluations

The radiation shielding activities for this reporting period have consisted of updating some of the previous evaluations with a new set of spent nuclear fuel characteristics, evaluating a concrete sleeve for fully self-shielding waste packages, and initial work for waste packages containing boiling water reactor spent nuclear fuel assemblies. The results of these evaluations have been reported elsewhere (CRWMS M&O, 1994a).

Activity 1.10.2.3.1 - Thermal. The thermal response of the near field has been studied for large waste packages such as the multi-purpose canister with disposal container. The thermal evaluation was divided into three parts. The first part is an analysis of the repository and emplacement drift thermal behavior. The second part is an analysis of the near-field and internal waste package thermal behavior with boundary conditions from the repository analysis. The third is an analysis of peak spent nuclear fuel cladding temperatures based on spent nuclear fuel basket temperatures. Finite element models were developed for each of the three parts.

A three-dimensional finite element model of the waste package emplacement was constructed to parametrically determine near-field thermal behavior for different thermal loadings and waste package concepts (CRWMS M&O, 1994f). The three-dimensional model was used to predict waste package temperatures for high and low thermal loadings. At high thermal loadings, waste package surfaces were above the boiling point for more than 1000 years. At low thermal loadings, a significant difference in near-field temperatures was observed between small and large waste package spacings at the same areal mass loading.

Peak spent nuclear fuel temperatures typically occur within a few years, but peak rock surface temperatures are typically reached only after tens of years. Since the peak spent nuclear fuel temperature occurs early, waste package spacing is more important than drift spacing in meeting the maximum spent nuclear fuel cladding temperature of 623 K. In an

open drift, the waste packages will interact by radiating heat down the length of the drift. Larger waste package spacings result in a larger heat sink area and lower near-field temperatures. Heat moves into the rock more slowly and drift-to-drift thermal interaction will not occur until at least ten years after emplacement. Because of the importance of the first few years to the fuel cladding, a minimum waste package spacing for a given package capacity and thermal output could be derived that is otherwise independent of thermal loading.

A spent nuclear fuel aging analysis was conducted for the 21 pressurized-water reactor assembly waste package. A spent nuclear fuel age of greater than 100 years (for an areal mass loading of 6.0 kg U/m^2) would be required to maintain waste package surface temperatures below the zone of aggressive aqueous corrosion (333 to 373 K). An average spent nuclear fuel age of 40 years would be required to maintain waste package surface temperatures below 373 K (boiling point).

Backfilling has not been considered. Analyses of thermal transients at the time of backfilling will be performed when better rock and backfill properties are available.

Benchmark calculations were performed to compare the three-dimensional emplacement model to analyses performed at two national laboratories. The results were favorable and identified the limitations in the assumptions used to develop each of the models. At this time, no single model can adequately describe all of the aspects involved in repository thermal loading.

A key thermal goal for waste package design is the 623 K cladding temperature limit. Peak cladding temperatures in the waste package can be determined by assuming an effective conductivity in the waste package model, applying the Wooton-Epstein correlation, or using a finite element model that represents a spent nuclear fuel assembly in the waste package. A finite element model of a spent nuclear fuel assembly was developed to investigate the thermal behavior of a spent nuclear fuel assembly with a dry fill gas or filler material and to develop a better basis for determining the effective thermal conductivity of an assembly with smeared/homogeneous properties (CRWMS M&O, 1994g).

Over-prediction of spent nuclear fuel cladding temperatures due to excessive conservatism can constrain design and limit waste package capacity. Preliminary results indicate that the spent nuclear fuel model is more accurate (and less conservative) than other approaches for predicting cladding temperatures. Further, using spent nuclear fuel model results, the calculated effective conductivities for a smeared-property spent nuclear fuel assembly were found to be primarily a function of temperature. Reliable spent nuclear fuel smeared properties could be used in the waste package thermal model to predict cladding temperatures and could allow thermal analysis with only two models.

Activity 1.10.2.3.2 - Structural. Structural analyses include preliminary analyses of the effects of rock falls on drift-emplaced waste packages, outer barrier and basket critical buckling loads, normal loading of basket members, and canister drops.

A finite element model was used to explore the resistance of a multibarrier waste package to rock falls. The elastic-plastic response of the waste package was determined for three drop heights corresponding to the Starter Tunnel, Exploratory Studies Facility tunnel, and emplacement drift tunnel sizes. Preliminary results indicate that the waste package can withstand an impact of a 20,000 kg rock falling 8.4 m without the breaching of any barriers.

Preliminary analyses have been conducted to determine the robustness of outer barrier and basket designs. In the basket analysis, an individual structural stage was examined and determined able to withstand a large load while still supporting fuel assemblies and filler material. The outer barrier was likewise determined able to withstand a large end load.

A waste package must be able to withstand handling accidents such as drops. A series of canister drop finite element analyses has been started. Simulations will evaluate the effects of 2-m drops and will focus on end drops, corner drops, and slap down drops onto an essentially unyielding surface. A model has been developed for the impact of a waste package on an essentially unyielding surface. Initial calculations have been run, but modifications of the elastic-plastic material definitions are required for the simulations to be as realistic as possible.

Activity 1.10.2.3.3 - Criticality. The primary focus of criticality evaluations was on the application of burnup credit. Other criticality activities addressed include the use of the multi-purpose canister for disposal, the use of moderator displacement filler material, the use of disposal criticality control rods, consideration of DOE spent fuel, long-term isotopics, and development/evaluation of the 12 pressurized-water reactor assembly waste package with interlocking basket for uncanistered fuel.

The activities performed in support of burnup credit include assistance for technical exchanges with NRC on burnup credit, assistance in the writing of the Storage and Transportation Burnup Credit Topical Report, efforts to acquire additional fission product cross sections for burnup credit criticality calculations, and continuing efforts to refine the methodology for disposal criticality control using burnup credit. Work has continued on determining which isotopes are important to long-term criticality control. The tools for developing the methodology to account for long-term depletion/transmutation of isotopes are being put together.

A paper was written concerning the long-term disposal criticality control considerations (CRWMS M&O, 1994h). In addition to describing the process for evaluating long-term criticality control and burnup credit, the paper also presented preliminary results for alternative criticality control options, including moderator displacement filler material, and disposal criticality control rods. The evaluations found the alternatives to be promising, but no single alternative could provide the long-term criticality control for all the fuel.

A criticality evaluation model for the 12 pressurized-water reactor assembly waste package with interlocking basket for uncanistered fuel has been created and is being tested.

A methodology has been developed for estimating the probability of waste package criticality from hazards from the post-emplacement environment. This method is based on defining six steps of progressive waste package degradation and disturbance that ultimately lead to criticality:

- Water infiltration rates greater than 1 mm/year for the repository area
- Channeling of moisture into cracks/fractures which drip directly on the waste package
- Container breach
- Leaching of neutron absorber material by water
- Structural non-failure (Criticality can occur only if the fuel assembly remains relatively intact so that there is sufficient inter-rod spacing for moderating water.)
- Ponding (Criticality can occur only if moderating water remains between the rods of a sufficient number of assemblies.).

The probability of occurrence of these steps, and their severity when they do occur, is determined by environmental parameters. The probability of criticality is determined by the probability and severity of each of the above six steps. These parameters have been grouped into seven scenarios. In the nominal scenario, infiltration is due to present precipitation and evaporation; concentration of water is due to observed major cracks; breach from corrosion is due to the limited concentrations of mineralogic corrosives. If backfill or waste package filler material are added, the nominal scenario is modified to the backfill and filler scenarios. Occurrence of enhanced corrosion or climate change lead to two additional scenarios. Finally, the "crack increase" and "tectonic disaster" scenarios occur if there is an increase in the density of cracks which concentrate water flows or rising of the water table and flooding of the repository, respectively. The level of risk will be estimated after the site characterization activities produce more realistic values of the natural environmental parameters, and after further research into the corrosion mechanisms.

Activity 1.10.2.3.4 - Cost Estimation. Several conceptual design drawings have been developed with improved descriptions of the design details. These have allowed more accurate determinations of the amount of material needed and have improved the accuracy of cost estimates.

Forecast: Results from the depletion/transmutation should be available during the next reporting period. Results of actual calculations from the criticality evaluation model for the 12 pressurized-water reactor assembly waste packages should be available by the time of the next progress report.

5.1.4 Design Activity 1.10.2.4 - Material Selection Design Support

A workshop was held to discuss plans for testing of container materials. The purpose of the workshop was to discuss what materials may be used for the multibarrier disposal container, what environments are meaningful for testing, and what kinds of tests should be performed. Much of the emphasis was on long-term testing (up to five years of exposure) because recent Project impetus is on substantially complete containment and on making an application for construction authorization. A summary of the workshop is being prepared, and the recommendations are being incorporated into the revised Metal Barrier Scientific Investigation Plan and into the Engineering Materials Characterization Report for input to the Controlled Design Assumptions Document.

UNS N08825 was selected as the reference material for a highly corrosion-resistant inner barrier, and ASTM A 516 (UNS G10200), a plain carbon steel, was selected as the reference material for the corrosion-allowance outer barrier. A third, moderately corrosion-resistant metal barrier, preferably made of suitable nickel-base material such as UNS N04400, was also proposed for mitigating microbiologically-influenced corrosion in wet environments. Alternative materials were also identified.

Activity 1.10.2.4.2 - Container shell. Progress in selection of container shell materials is described under Activity 1.10.2.4.1.

Activity 1.10.2.4.3 - Shield plug. A shield plug is a design feature of the multi-purpose canister, not the disposal container. Accordingly, no additional effort has been made in selecting shield plug materials.

Activity 1.10.2.4.4 - Spent nuclear fuel basket (structural). Progress in selection of basket materials is described under Activity 1.10.2.1.1.

Activity 1.10.2.4.5 - Spent nuclear fuel basket (criticality). Progress in selection of basket materials is described under Activity 1.10.2.1.1.

Activity 1.10.2.4.6 - Filler material. Iron shot remains the first choice for filler material. Current efforts are described in Section 5.5.5. A technical requirements document has been drafted for measurements to be made on bulk thermal conductivity of iron shot.

Activity 1.10.2.4.7 - Fill gas. Helium remains the primary choice for fill gas.

Forecast: Work on materials selection will continue. A quality affecting collection of materials properties will be completed.

5.1.5 Design Activity 1.10.2.5 - Performance Evaluations

Activity 1.10.2.5.1 - Container oxidation and corrosion. A model has been developed for the contribution of the corrosion-allowance material to containment life (McCoy, 1994a). Corrosion depths were calculated for the expected environment (humid air) and for several types of enhanced corrosion.

The model is based on the equation of Stahl (1993) for immersed, aqueous corrosion of low carbon steel. The equation was extended by adapting it to describe atmospheric general corrosion in humid air. For saturated air, the equation reduces (conservatively) to Stahl's equation. To apply the model to a repository, temperature and humidity results from a repository-scale model with a smeared disk-shaped heat source were used.

At low mass loadings, humidity remains high and rapid corrosion is seen at short times. At higher mass loadings, however, the relative humidity drops and corrosion is suppressed. Suppression of corrosion can last for thousands or tens of thousands of years. For all of the mass loadings and locations considered, the corrosion lifetime is greater than 10^5 years under expected repository conditions. No evidence is found that high mass loadings will lead to early, catastrophic failures. At sufficiently long times (~10^5 years), the repository environment returns to approximately its initial temperature and humidity, so the corrosion behavior at very long times is essentially independent of the mass loading.

Unexpected conditions were modeled by performing a sensitivity study in which the parameters for the corrosion equation were changed. Unprotective oxides were handled by increasing the time exponent in Stahl's equation, and microbiologically influenced corrosion and pitting were handled by increasing the rate constant. As expected, less protective oxides and larger rate constants lead to earlier failures. These effects can be mitigated by using a high mass loading.

Activity 1.10.2.5.2 - Waste package degradation by mechanical stress. Activities on stress analysis are described under Activity 1.10.2.3.2.

Activity 1.10.2.5.3 - Thermal degradation of fuel cladding. There was no activity during the current reporting period. Work will resume in FY 1995.

Forecast: Calculations of container oxidation and corrosion will be extended to include the effects of local heating.

5.2 POSTEMPLACEMENT NEAR-FIELD ENVIRONMENT (SCP SECTION 8.3.4.2)

5.2.1 Design Activity 1.10.1.1 - Consideration of 10 CFR 60.135(a) Factors

Aqueous corrosion rates for waste packages may be significantly enhanced if the waste package environment is hot and humid. With large multi-purpose canisters, corrosion can be controlled either by minimizing how long a humid repository remains hot or maximizing how

long a hot repository remains dry. Both strategies aim to minimize the likelihood and duration of hot and humid waste package conditions.

Analyses were conducted to evaluate an assumption of Total System Performance Assessment - 1993 (Wilson et al., 1994; Andrews et al., 1994) that waste packages rewet at the end of the boiling period. The new calculations show that the assumption is flawed. At the end of the boiling period, high thermal loads give lower humidities than low thermal loads. The assumption that corrosion initiates at the end of boiling is therefore more conservative for the high thermal loads.

Repository-scale model calculations were re-examined with an emphasis on temperature and relative humidity. Relative humidities above 70 percent were emphasized, because preliminary work on waste package corrosion indicates that this is an approximate threshold for significant aqueous corrosion. Similarly, a temperature of about 60°C is thought to be an approximate threshold for enhancement of aqueous corrosion processes relative to lower temperatures. For intermediate areal mass loadings, significant fractions of the repository never dry below 70 percent relative humidity, and all of the repository rewets back to 80 percent relative humidity before temperatures drop below the nominal boiling temperature. These conditions may be very corrosive to waste packages. A very high areal mass loading has considerably better performance, requiring many thousands of years to rewet and providing a lower temperature when rewetting occurs. Both the areal mass loading and the distribution of areal mass loading can affect the duration of benign conditions.

A repository scale thermohydrological model was used to investigate the sensitivity of the relative humidity and temperature at various locations in the repository to the gas-phase diffusion efficiency. In general, the effect on temperature and relative humidity behavior is relatively minor. Gas-phase rewetting is likely to dominate for humidities of about 70 percent to 80 percent. Subsequent rewetting to ambient relative humidity conditions is dominated by liquid-phase rewetting.

Repository-scale thermohydrological calculations were conducted for six sets of matrix properties: those of the Reference Information Base and the five sets of Topopah Spring welded tuff properties listed in Pruess and Tsang (1994). The duration of the boiling period was found to be insensitive to the range of matrix properties considered. Five of the six property sets produced similar relative humidity conditions at the end of the boiling period for various areal mass loadings. The sixth property set results in a substantially faster liquid-phase rewetting rate and more humid conditions by the end of the boiling period. Enhanced vapor diffusion can enhance the rate of heat loss from the repository, modestly decreasing the time above boiling and reducing the relative humidity at the end of the boiling period, particularly at the repository edge.

Five backfill strategies have been evaluated, and their effects on waste package performance and life have been studied (CRWMS M&O, 1994i). The five are no backfill, crushed tuff, concrete, dry concrete mix, and a two-layer backfill with coarsely crushed material surrounding the waste package and a layer of fine material on top. Using no backfill is inexpensive and simple and facilitates dissipation of heat from the waste. Backfill protects

against rock fall but thermally insulates the waste, increases the mechanical load on the waste package, and may have an unpredictable effect on water chemistry. Controlling placement of backfill in a long drift will be difficult.

Forecast: Thermohydrological calculations will continue in support of the Thermal Loading Systems Study.

5.2.2 Study 1.10.4.1 - Characterize Chemical and Mineralogical Changes in the Postemplacement Environment

The draft study plan for Waste Package Geochemistry and Mineralogy was reformatted to meet the requirements of the DOE-NRC agreement and is currently in DOE review.

Work at the New Zealand natural process analog site is emphasizing evaluation of the way in which model validation activities can be conducted in the field. Data have been collected and compared against simulations which demonstrate that very good agreement can be achieved between the two. However, perfect matches are impossible because of uncertainties in thermodynamic property measurements and limitations of conceptual models. As a result, attention is being focused on developing strategies that allow a more flexible approach to validation efforts. This will be important when validation efforts address characterization of processes and properties of the site.

Activity 1.10.4.1.1 - Rock-water interactions at elevated temperatures. Studies of the effect of changes in relative humidity on rocks that occur within the vicinity of the repository horizon were started to determine the effect of changes in humidity on rock-water interaction. These studies will evaluate the rates of reaction, the extent and mechanism of reaction, and the impact on water chemistry.

Work in the New Zealand natural process analog site is designed to (1) develop conceptual and analytical models of dissolution and precipitation kinetics by resolving conflicts between laboratory-based and field-based measurements, (2) test thermodynamic data and modeling techniques by simulating rock-water interaction in hydrothermal systems, (3) develop techniques and strategies for using natural systems to accomplish code and model testing, and (4) define the uncertainty that bounds simulations and projections of geochemical processes. To initiate studies that address kinetics issues, field-based experiments have been started at the New Zealand site. Materials selection for sample holders and frames was completed. Samples of materials and minerals for study were selected and prepared for emplacement. To evaluate discrepancies between measurements, a field-based study was started to evaluate the mechanisms and controls on silica precipitation in concrete-lined drain fields.

Activity 1.10.4.1.2 - Effect of grout, concrete, and other repository materials on water composition. This activity is now reported under Activity 1.10.4.5.1 as a result of changes to the Site Characterization Program Baseline, Revision 8.

Activity 1.10.4.1.3 - Composition of vadose water from the waste package environment. No progress during the reporting period; this was an unfunded activity.

Activity 1.10.4.1.4 - Dissolution of phases in the waste package environment. No progress during the reporting period; this was an unfunded activity.

Activity 1.10.4.1.5 - Effects of radiation on water chemistry. This activity is discussed under Activity 1.10.4.5.3 because the activity was divided between geochemistry and man-made material activities in the Site Characterization Program Baseline, Revision 8.

Activity 1.10.4.1.6 - Effects of container and borehole liner corrosion products on water chemistry. This activity is reported under Activity 1.10.4.5.2 as a result of changes to the Site Characterization Program Baseline, Revision 8.

Activity 1.10.4.1.7 - Numerical analysis and modeling of rock-water interaction. This activity is also reported under Activity 1.10.4.5.1 because the activity was divided between geochemistry and man-made material activities in Site Characterization Program Baseline, Revision 8.

To test thermodynamic data and modeling techniques, methods were developed in which the affinity of relevant mineral phases is computed. The results identify likely stable mineral assemblages which are then compared to observed mineral assemblages. Preliminary results demonstrate that, although very good agreement can be achieved, perfect matches are impossible because of uncertainties in the thermodynamic data, thermodynamic property measurements, limitations of conceptual models, and uncertainties in the analytical data. This information is being used to develop methods for defining uncertainty envelopes around geochemical forecasts.

Forecast: Relevant portions of Study 8.3.1.3.3.1 (Natural Analog of Hydrothermal Systems in Tuff) will be considered for incorporation into this study. Study Plan 8.3.1.3.3.1 has been eliminated as a result of the study plan work scope consolidation effort.

5.2.3 Study 1.10.4.2 - Hydrologic Properties of Waste Package Environment

Responses were provided to comments on the Study Plan for Hydrological Properties of Waste Package Environment. The reviewers are considering the responses.

Activity 1.10.4.2.1 - Single-phase fluid system properties. Experiments continued to determine the effect of confining pressure on fracture healing. Permeability of fractured Topopah Spring tuff as a function of temperature and confining pressure is being determined. After heating, the water permeability under confining pressures is decreased. No drastic fracture healing was observed. Steam flow at 125°C had no significant effect on permeability. Some water samples were examined for bacteria, and no evidence of bacteria colonies was observed.

Activity 1.10.4.2.2 - Two-phase fluid system properties. Electrical impedance has been proposed a parameter for measurement of moisture content. Experiments are ongoing to test this hypothesis. The complex nonlinear least squares method is being used to fit the electrical impedance vs. saturation data. The results can be used to distinguish different phases of the water wetting/drying processes. The wetting phase measurements at 95°C were completed. Analysis indicates that the measurements may be useful in describing the manner in which water wets rock. Several conduction mechanisms are observed that change in importance with changing saturation levels. Additional study is under way to determine the nature of each conduction mechanism. Completion of this work will simplify the task of measuring water distribution in thermohydrological experiments at laboratory and field scales.

Experiments to determine the moisture retention and one-dimensional imbibition of G-4 core continue. The data will be used to calculate relative permeability as a function of water saturation. A new sample holder and bagging system were designed to prevent pooling of water and dry-out during weighing. Moisture retention experiments at high temperatures are in progress. Measurements at 95°C and up to 95 percent relative humidity are complete. The one-dimensional imbibition data were analyzed. The propagation of the saturation front determined by electrical resistivity measurement was compared with an analytical model. The agreement was very good.

The experiment to calibrate a resonant cavity for measuring suction potential as a function of moisture content has resumed. Apparatus for computerized collection of resonant spectra was installed and tested. The high temperature constant humidity chamber will be used to calibrate the cavity at temperatures above the boiling point of water. The resonant frequencies of five cavities were measured at room temperature and ambient humidity.

The evaluation of x-ray scan as a technique for monitoring moisture content distribution in a rock sample has begun. Using water doped with iodide as saturation fluid increased the resolution of the saturation level by a factor of two.

Activity 1.10.4.2.3 - Numerical analysis of flow and transport in laboratory systems. The experiments and analyses described in the other two activities of this study are not yet linked. The experiments are measuring properties and single phenomena at a small scale. The analyses are primarily for mid-to-large scale coupled effects. For this activity, each paragraph describes a separate set of calculations or analyses performed by the investigators.

The study plan for Laboratory Determination of Hydrological Properties of the near-field environment has been reviewed by YMSCO. The author is resolving comments.

A detailed analysis was conducted of the thermohydrological effects of repository heat near the ground surface, in response to an invitation by NWTRB. Because of the interest in the repository-heat-driven effects on the shallow terrestrial ecosystem, attention was focused on the upper three meters of Yucca Mountain, which corresponds to the root zone. The primary mode of repository-driven heat flow to the ground surface is heat conduction. Temperature rise at the ground surface will be no less than that predicted by "heat conduction only" models. Mountain scale, buoyant, gas-phase convection can enhance the temperature

rise near the ground surface for tens of thousands of years, depending on the permeability values used, but surface temperature increases of more than a few degrees are not expected.

A primary concern for repository performance is how water contacts a waste package, thereby affecting its integrity and, if containment is breached, radionuclide dissolution and transport. There are two primary modes of water contact: advective liquid flow and condensation of water vapor of the waste package surface.

Thermohydrological calculations were carried out for six sets of matrix properties of the TSw1 and TSw2 units. These properties were shown to have a strong influence on both the time for return to a relative humidity that could accelerate corrosion and on the temperature at which the humidity returns. Since corrosion will be accelerated when both temperature and humidity are high, it is important to be able to accurately calculate these parameters.

As discussed in Section 5.2.1, thermohydrological simulations have addressed the impact of enhanced gas-phase diffusion and the sensitivity to matrix hydrological properties. Enhanced vapor diffusion reduces the overall rewetting rate where the advective liquid-phase rewetting rate is fastest. Therefore, enhanced gas-phase diffusion may be thought to function somewhat as an equalizer of thermohydrological conditions, countering some of the effects of heating variability and heterogeneity in various hydrological properties.

Thermohydrological sensitivity studies were conducted to determine the impact of small bulk permeability on temperature and relative humidity conditions at the repository. A substantial reduction in bulk permeability K_b can result in a substantial increase in gas-phase pressure, thereby suppressing vaporization and (possibly) dry-out. For moderate thermal loads, a small K_b can substantially throttle the rate of boiling, thereby reducing the duration of low relative humidity conditions. The impact of small K_b on high areal mass loadings was found to be quite different. The duration of low relative humidity conditions was sometimes actually increased.

Thermohydrological models were used to analyze the impact of an optimized areal mass loading distribution and enhanced gas-phase diffusion on temperature and relative humidity conditions in the repository. One of the major objectives of the optimized, nonuniform areal mass loading distribution is to produce more uniform temperatures and relative humidities. Relative humidity is most uniform during the above-boiling period. The time to rewet to humid conditions will vary, depending on proximity to the repository edge or and geological heterogeneity. Increasing the mean time to rewet to humid conditions will tend to result in generally lower temperatures once relatively humid conditions have been restored, and perhaps more important for controlled release, in a greater variation in aqueous corrosion rates from place to place within the repository. Variation in corrosion rates will tend to distribute waste package failures in time.

This work is described in Buscheck and Nitao (1994) and Buscheck et al. (1994).

Forecast: An interim report on hydrological properties measurements will be released. Comments on Revision 0 of Study Plan 8.3.4.2.4.2 will be resolved by the author and the remaining section of the study plan, dealing with modeling, will begin review. This remaining section will ultimately be included in Revision 1. Finally, the initial QA baseline of the V-TOUGH code will be completed.

5.2.4 Study 1.10.4.3 - Characterization of the Geomechanical Attributes of the Waste Package Environment

Activity 1.10.4.3.1 - Block stability analysis.

Geomechanical Modeling of the Large Block Test is described in Section 5.2.5.

In support of the Large Block Test, the geomechanical response of the fractured rock system to mechanical and thermal loads is being studied, and mechanical data for the hydrological and geochemical investigations are being measured. The geomechanical investigations include modeling studies of the thermomechanical response of the large block.

Geomechanical studies on the large block are focused on (1) the overall rock mass deformation vs. applied stress, temperature and time; (2) the decomposition of the deformation into components due to deformation of fractures and matrix material; and (3) the effect of temperature and related movement of fluids and geochemical effects on deformation, rock damage, and static and dynamic properties. Geomechanics measurements planned for the Large Block Test include static deformation, monitoring of acoustic emission, and acoustic tomography. All fractures on the surface and in boreholes are being mapped to provide additional constraints on the block structure.

The purpose of the modeling is to aid in the experimental design and to evaluate various thermal and material models, and numerical methods for predicting the block response. The geomechanical response is being analyzed using a time-dependent finite difference method, a discrete element method, and the boundary element method. The finite difference code treats both mechanical and thermally induced stresses and deformations. Studies done using the finite difference code have assumed that the sides of the block will be thermally insulated and the temperature at the top will be held at 20°C. The preliminary test design calls for five heaters to be located in the rock to simulate a plane heat source and establish a boiling zone. Initial simulations used a purely elastic constitutive model. Simulations using other constitutive models are under way.

Analysis of the mechanical behavior at test conditions of the blocks and fracture system is also currently under way using the discontinuous displacement analysis approach discussed by Shi and Goodman (1985). Recent progress includes digitizing the fracture map into a form suitable for input into a discrete element code, with discrete blocks defined and the coordinates of vertices listed, and production of numerical modules for display of the discrete blocks once they are digitized and post-processing and graphic display of stresses and displacements.

A limited study was conducted to assess the stresses generated in the rock mass by the rock bolt anchoring system to be used to anchor the Large Block Test loading frame. Three rock bolts were simulated and the bolts were assumed to be anchored along their entire length. The compressive stresses are well below the strength of the rock mass. Further analysis is under way that incorporates a more accurate geometry for the rock bolts, and the results will be used to assess the rock bolt design for the anchoring system.

Activity 1.10.4.3.2 - Borehole damage analysis. No progress during the reporting period; this was an unfunded activity.

Activity 1.10.4.3.3 - Geomechanical properties analysis. Small block laboratory tests (0.5 m scale) are intended to clarify the thermomechanical, thermohydrological, and thermochemical response of the rock to conditions similar to the near-field environment of the proposed repository, and to conditions expected during the Large Block Test. The tests were designed, an activity plan was prepared and approved, a laboratory apparatus was prepared, four small block samples were prepared, diagnostic equipment was obtained, and a series of engineering tests was conducted to evaluate materials for boundary heaters.

A series of three tests is to be conducted on small blocks of rock collected during excavation of the large block at Fran Ridge. Properties to be measured include (1) the matrix thermal expansion, (2) thermally-induced displacement across fractures, (3) rock mass thermal expansion of block samples containing fractures, (4) rock mass deformation modulus and fracture stiffness, and (5) elastic wave velocity. Details of test objectives, materials and apparatus to be used, and planned test procedures are given in Activity Plan AP-GM-01/GM-03/GM-05.

Four boulders, approximately 0.5 to 1 m in diameter, were collected from the surface excavation level of the Large Block Test site. The boulders were cut into rectangular samples. Quality affecting samples for the small block tests were also collected from the Large Block Test site. Samples were also obtained between the top of the large block and a depth of 4 m, on all four sides of the large block. Some samples broke during removal, because of the many natural fractures in the rock mass. A subset of these samples is intended for use in the laboratory tests of small blocks. A 300-ton loading frame capable of accommodating both the size and required force necessary for testing the small block samples was reconditioned and reconfigured for testing tuff samples.

Several diagnostic systems will be used on the small block samples, including systems for measurement of displacement at different length scales and in different directions, axial load, acoustic emission, elastic wave velocity, temperature and other parameters. Transducers for the displacement, load, and temperature have been procured and are currently being installed either on the test apparatus or on the test specimen as appropriate. A fiber-reinforced calcium silicate material known as Marinite was tested under temperature and pressure conditions similar to those of the Large Block Test and small block laboratory tests and found to be a suitable insulation for both types of tests.

The source probe used in the G-Tunnel experiment was found to be useful for the Large Block Test, and the type of pulse generator used in the G-Tunnel experiment would work for both the Large Block Test and for laboratory tests of small blocks. An updated version of the pulse generator could be purchased in the next fiscal year.

Forecast: During FY 1995 more realistic constitutive models will be used in the continuum calculations, and the discrete element analysis will be evaluated. Testing of the first of the small block samples is expected to begin in October 1994.

5.2.5 Study 1.10.4.4 - Engineered Barrier System Field Tests

Activity 1.10.4.4.1 - Repository horizon near-field hydrologic properties. The large block was placed in vertical compression using rock bolts, and the rock surrounding the large block was removed. Over 500 samples were taken. A wire saw was used to remove the top. Fractures on the five exposed faces were mapped.

The vendor for the reaction frame experienced difficulty in meeting specifications. Additional structural analysis was conducted to determine the allowable load and safety factor. Three fracture flow visualization experiments were conducted adjacent to the large block. Electrical resistance tomography was used to track the liquid infiltration. Food dye was used as a tracer, and the pathways were mapped during subsequent excavation of the rock around the large block. On two of the three sites, some dye was visible all the way to the bottom of the 4.5-m excavation. The post-sawing neutron logging to estimate the effect of the sawing procedure on the initial moisture content in the large block was completed. There was only a slight increase in moisture content after the sawing which used water as a coolant.

Mercury porosimetry measurements were made on large block core sections. The average bulk matrix porosity is about 11.55 ± 2.28 percent. There appears to be a systematic increase of porosity with depth. Preliminary results also indicate that porosity increases with increasing distance from a fracture. Additional samples for using the wet-dry method of determining porosity were prepared.

A temperature control unit was ordered for the heat exchange system which will be installed on the top of the block. The design of the heat exchange system is based on thermal conduction model calculations. A potential manufacturer for the bladders was selected. The engineering design of the bladder support/housing devices began.

Activity 1.10.4.4.2 - Repository horizon rock-water interaction. No progress during the reporting period; this was an out-year activity.

Activity 1.10.4.4.3 - Numerical analysis of fluid flow and transport in repository horizon near-field environment. Thermohydrological calculations were performed to support the Large Block Test.

Forecast: The Large Block Test load retaining frame sections will be completed and inspected using non-destructive evaluation techniques. Study Plan 8.3.4.2.4.4 will be submitted to NRC.

5.2.6 Study 1.10.4.5 - Characterize the Effects of Man-Made Materials on Water Chemistry in the Postemplacement Environment

Activity 1.10.4.5.1 - Effect of grout, concrete, and other repository materials on water composition. A diesel exhaust study was initiated to provide information useful in determining whether diesel or electrical equipment will be used in the Exploratory Studies Facility.

Chemical information on diesel exhaust in the literature is neither explicit nor complete, and none of it establishes mechanisms that might be used to predict long-term behavior. In addition, the data regarding microbially mediated chemical reactions is not well correlated with the abiotic chemical data. To obtain some of the required long-term information, the U12n tunnel at Rainier Mesa, Nevada Test Site, was chosen as a historical analog. The thick layer of dark deposit at the sample site was assumed to consist primarily of rock powder and diesel exhaust. Surface samples and core samples were collected and analyzed to measure both spatial distribution and concentration for the wide variety of chemical components that was expected based on the literature survey.

Preliminary computer chemical simulations were conducted using the EQ3/6 geochemical modeling code and a simplified version of the chemical analysis of the surface deposit. The other modeling exercise originally planned, using analyses from the literature, proved to be impossible due to inexplicit information. Given time and data base restrictions for the present study, and thus the inability to conduct a full spectrum of simulations, an open system was assumed with all the carbon in elemental form, with a potential of being converted to carbonate. The pH was considerably affected, which ultimately affected which phases were predicted to dissolve or precipitate. These results are considered to represent one extreme bound for the potential chemical modification of natural waters.

The analysis of microbiota that may be affected by diesel fuel and diesel exhaust provides a first step in describing microbially mediated chemistry. Total cell counts and numbers of various types of bacteria were obtained. Samples were taken from three depths into the walls and invert. In general, the tunnel invert, a perturbed environment, demonstrates a greater abundance of specific bacterial types than does the tunnel wall. However, the trends recorded in culturable counts of aerobic heterotrophic bacteria with depth in the wall and the invert were the inverse of each other. The counts increased with depth into the wall and decreased with depth into the invert. Microbes capable of using diesel fuel and diesel combustion products were present in both the tunnel wall and the invert.

These results of this historical analog study emphasize the need for further investigation into the effects of diesel exhaust. This study also provides a template for the type of integrated approach, using both microbiological and chemical tools, that the Man-Made

Materials Task requires to determine and predict the long-term chemical consequences of the presence of introduced materials.

The 200°C H_2O-fibercrete™ control experiment was completed and the experiment disassembled. The 200°C H_2O-diesel fuel-fibercrete™ experiment and 200°C H_2O-diesel fuel-fibercrete™ -tuff experiment were initiated.

Activity 1.10.4.5.2 - Effects of container and borehole liner corrosion products on water chemistry. No progress during the reporting period; this was an unfunded activity.

Activity 1.10.4.5.3 - Effects of man-made materials in presence of radiation field. No progress during the reporting period; this was an unfunded activity.

Activity 1.10.4.5.4 - Numerical analysis and modeling of man-made materials/water interaction. No progress during the reporting period; this was an unfunded activity.

Forecast: Comments on Study Plan 8.3.4.2.4.5 will be resolved by the author. Studies of the effects of diesel exhaust in the Exploratory Studies Facility will continue.

5.3 CHARACTERISTICS AND BEHAVIOR OF THE WASTE FORM (SCP SECTION 8.3.5.10)

5.3.1 Activity 1.5.1.1 - Integrate Waste Form Data and Waste Package Design Data

Subactivity 1.5.1.1.1 - Integrate spent fuel information. The preliminary Waste Form Characteristics Report (Stout, in prep.) was approved by YMSCO for publication.

Subactivity 1.5.1.1.2 - Integrate glass waste form information. The preliminary Waste Form Characteristics Report was approved by YMSCO for publication. Work is also continuing on the collection and evaluation of borosilicate glass dissolution data obtained outside of the YMP for inclusion in the next version of the Waste Form Characteristics Report.

Subactivity 1.5.1.1.3 - Integrate waste package and repository design information. The M&O and LLNL participated in the preparation of the Controlled Design Assumptions document to be used as an initial basis for Advanced Conceptual Design of the Waste Package and Repository.

Forecast: Data from waste form characterization will be integrated into a draft revision of the Waste Form Characterization Report.

5.3.2 Activity 1.5.2.1 - Characterization of the Spent Fuel Waste Form

Subactivity 1.5.2.1.1 - Dissolution and leaching of spent fuel. A systematic effort has been ongoing for several years to determine the effect of temperature and water chemistry on the dissolution of the matrix of both unirradiated UO_2 and spent fuel. This effort includes the higher oxidation states of uranium because of the potential for oxidation of spent fuel in a repository.

An experimental test plan for the UO_2 experiments at LLNL was written and approved. Twenty of these twenty-four planned experiments were completed or are in progress. The dehydrated schoepite dissolves much faster than the U_3O_8, particularly at high carbonate levels. The dissolution rates of U_3O_8 are very similar to those of UO_2 under analogous conditions. An experimental study was conducted to determine the dissolution-rate dependence of spent fuel on carbonate/bicarbonate concentration, pH, O_2 overpressure, and temperature. An unexpectedly complex dependence on a combination of O_2 overpressure and temperature was observed. The dissolution rate was almost independent of O_2 overpressure at 25°C but very dependent at 75°C. In contrast, an intermediate and nearly constant dependence was seen for unirradiated UO_2.

The gap and grain-boundary inventories of ^{137}Cs, ^{99}Tc, and ^{90}Sr were found to be 1 percent, 0.2 percent, and 0.2 percent or less of the total inventories for these nuclides, respectively. The question of ^{137}Cs dissolution rate from grain boundaries could become less important if the small grain-boundary inventories for ^{137}Cs indicated above are typical.

It has been common to assume that oxidized fuel would dissolve faster than unoxidized fuel. Scoping tests have been conducted to determine dissolution rates of specimens oxidized in air to U_4O_{9+x} and U_3O_8. Such oxidation increased the intrinsic dissolution rate by a factor of a few times. A more important effect of oxidation to U_3O_8 was the very large increase in surface area. Supplemental tests were also conducted with unirradiated U_3O_7 and U_3O_8. Their intrinsic dissolution rates were about two and three times, respectively, faster than for UO_2.

The observed dissolution rate in the flow-through test was about six times higher than in the static test. This difference is relatively small considering the difference in the nature of the tests. Dissolution rates of unirradiated UO_2 powder were measured using a flow-through method to address experimental replication issues. The measured rates agreed within a factor of three to four, which is considered reasonable agreement for this type of testing (Gray, 1994).

The following dissolution activities were scheduled to be conducted: (1) flow-through tests on oxidized U_4O_{9+x} and unoxidized pressurized-water reactor spent fuel specimens, (2) flow-through tests on pressurized-water reactor spent fuel at low pH (three to six), and (3) measurements of gap inventories and grain-boundary inventories of ^{129}I.

Unsaturated dissolution tests are in progress to evaluate long-term performance of spent fuel. These tests examine the leach/dissolution behavior of pressurized-water reactor fuels in

saturated water vapor atmosphere and in dripping water at two drip rates. Two years of tests are complete. These tests are being performed to provide bounding release rates for performance assessment studies and model validation. It is often assumed that the reaction of waste forms will be most rapid when contacted with large volumes of water. However, in tests with low volumes of water, the waste rapidly saturates small volumes of solution, secondary mineral phases form, and the distribution of radionuclides in the solution is completely different from that observed in tests with large volumes of water. The rate at which fuel oxidizes in the presence of small volumes of water and air is so rapid that prior oxidation of the fuel during storage is unlikely to affect total radionuclide release, except that dry oxidation which results in cladding rupture would expose a greater surface area of fuel to reaction.

Drip tests on unirradiated UO_2 pellets have been ongoing for 7.5 to 8.8 years. Results from these tests suggest that altered phases form in a specific sequence. Natural systems show the same sequence of phase formation, suggesting that tests with a low volume of water accurately simulate natural processes.

Subactivity 1.5.2.1.2 - Oxidation of spent fuel. Long-term oxidation tests with several light-water reactor spent fuels representing a wide range of burnup and gas release conditions are being performed in dry baths. The purpose of the tests is to provide the scientific basis needed to assess the long-term oxidation behavior of spent fuels under repository conditions. Additionally, the dry-bath tests provide oxidized material for dissolution tests. Complementary to the dry-bath tests is a series of higher temperature continuous-weighing thermogravimetric analysis tests.

Testing of several spent fuels in dry-bath oxidation ovens at 110 to 195°C and times up to 50,000 hours has revealed no further significant changes beyond the metastable $UO_{2.4}$ state established at shorter times. The $UO_{2.4}$ phase appears to persist indefinitely at these temperatures.

In tests conducted with the same as-irradiated fuels at 255°C, oxidation proceeded to average oxygen-to-metal ratios as high as 2.6 after 9000 hr. Preoxidized spent fuel consisting of ~100 percent $UO_{2.4}$ remained near the initial oxygen-to-metal ratio of 2.4. The different oxidation behavior of the preoxidized and as-irradiated samples in the 255°C tests is not understood. X-ray diffraction analysis of samples with an oxygen-to-metal ratio between 2.4 and 2.56 indicated that oxidation beyond $UO_{2.4}$ proceeds either by solid state amorphization or by formation of nanocrystalline U_3O_8 (most likely the latter). Analysis of the $UO_{2.4}$ x-ray peak broadening indicated that the $UO_{2.4}$ to U_3O_8 transformation strained the lattice of the oxidized fuel and reduced the $UO_{2.4}$ crystallite size.

Eight thermogravimetric analysis tests with spent fuel have been completed or are in progress. They confirm that the oxidation of spent fuel proceeds primarily by two reactions, from UO_2 to $UO_{2.4}$ and the from $UO_{2.4}$ to $UO_{2.75}$. Sample-to-sample variability effects have been observed and are attributed to sample-to-sample inhomogeneity of the relatively small (200 mg) test samples.

The plateau observed in the dry-bath tests is too long to measure on a laboratory time frame of a few months or years. The thermogravimetric analysis tests at higher temperatures are being used to determine the kinetics of U_3O_8 formation in order to develop a basis for predicting long-term oxidation behavior at repository temperatures. The results of the thermogravimetric analysis tests along with the dry-bath results should allow prediction of the length of time that a breached rod can remain at temperatures of repository interest before the effects of U_3O_8 formation appear.

Subactivity 1.5.2.1.3 - Corrosion of zircaloy. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.5.2.1.4 - Corrosion of and radionuclide release from other materials in the spent fuel waste form. The effects of control rods on disposal were evaluated (McCoy, 1994b). DOE (1994z) clearly states that control rods are part of spent nuclear fuel; therefore, control rods will be accepted from utilities. It is not clear, however, whether control rods will be emplaced with the spent fuel.

The neutron absorber in many control rods is an alloy of silver, cadmium, and indium. Cadmium is classified as a hazardous material by the Resource Conservation and Recovery Act of 1976, as amended (RCRA, 1976). Under current regulations, a repository must comply with provision of this Act. The Act and its implementing regulations impose strict controls on the release of cadmium from solid waste. Rough corrosion calculations suggest that, because of the significant corrosion resistance of silver, control rods are not a hazardous material.

Subactivity 1.5.2.1.5 - Evaluation of the inventory and release of carbon-14 from zircaloy cladding. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.5.2.1.6 - Other experiments on the spent fuel waste form. No progress during the reporting period; this was an unfunded activity.

Forecast: Dissolution and oxidation testing of six spent fuel Approved Testing Materials will continue. Acquisition of five additional Approved Testing Materials to complete the text matrix will be planned.

5.3.3 Activity 1.5.2.2 - Characterization of the Glass Waste Form

Subactivity 1.5.2.2.1 - Leach testing of glass. The Defense Waste Processing Facility 165 glass used in the N2 unsaturated dissolution tests has a different composition than the West Valley glass used in the N3 tests, and release of different materials may be anticipated. N2 colloids from three tests are similar in composition and size range. The two major colloidal phases are iron silicate smectite clay containing measurable (>1 wt percent) amounts of uranium and iron oxide. These phases are indeed different from those observed in the N3 tests. The surface charge is dependent on pH and the type of oxide. In most groundwaters, the surface charge is negative for clay colloids and positive for sols of

hydroxides such as $Fe_2O_3 \cdot xH_2O$ and $TiO_2 \cdot xH_2O$. Hence, there will be an electrostatic attraction between hydroxide sols and clay colloids. This effect has been observed in the tests from the N2 series and with metal oxides, such as TiO_2, in other tests. The commonly held view is that colloids should be retarded in tuff rock. However, the tuff rock can be covered by clay minerals which tends to repel clay colloids. These preliminary results may have a significant impact on radionuclide transport predictions if they are supported by additional data.

A scheduled solution sampling for the N2 tests at 101 months was completed. To perform the sampling and retain the correct interchange of vessels, stored liquid from the previous sampling period that was being saved for additional studies has been transferred to a glass storage vial. Sixteen parametric tests of Defense Waste Processing Facility and West Valley Demonstration Project glass are continuing; some have been in progress for up to eight years. No sampling has been done in several years, although solution injections will continue. Tests on a variety of glasses exposed to 60 percent and 95 percent relative humidity at 70°C continue.

An activity plan will be written to complete the planning for continuing these initial scoping experiments under full QA Program control.

Subactivity 1.5.2.2.2 - Materials interactions affecting glass leaching. Particles of iron oxide from the corroded Type 304L stainless steel (UNS S30403) sample retainer in the N2 tests attracted to the smectite clay particles released in the test. It is possible that this attraction may lead to agglomeration of material which will be less able to remain in solution.

Samples of colloidal materials were analyzed. There has been a continual interaction between the sensitized stainless steel and the glass. Many agglomerates were found that were rich in iron. These agglomerates were round particles about 1 μm in diameter. In other regions, clay was closely associated with iron particles and other elements including zinc. These clay phases were on the order of 100 nm in diameter. Calcium oxide particles on the order of 0.5 μm in diameter were also found. Several particles approximately 0.2 μm in size were isolated; they appear to be similar to the layers that form on the glass as it reacts. It appears that the reacted glass layer spalls from the glass surface as the water slowly drips over the glass.

Samples taken from the high-level waste dissolution tests were analyzed. The dissolution rate of lithium has been fairly constant over a period of eight years. Silicon is being removed from the liquid, but the rate is leveling off. There appear to be two competing processes: (1) addition of silicon to the liquid because of spallation of glass layers, and (2) removal of silicon as iron silicates which form on the metal sample holders.

Subactivity 1.5.2.2.3 - Cooperative testing with waste producers. No progress during the reporting period; this was an unfunded activity.

Forecast: Degradation testing of the glass waste form will continue. Additional colloids from previous tests will be analyzed.

5.3.4 Activity 1.5.3.1 - Integrate Scenarios for Release From Waste Packages

Subactivity 1.5.3.1.1 - Develop scenario identifications. Development of the YMIM code (Lamont, 1994) continued. Information pertaining to this development is provided in Section 5.3.8. This model combines summary models of many processes of the near-field environment and the Engineered Barrier System. Near-field processes are represented by their time-varying values at the waste package boundary. The resulting changes in the waste packages and waste forms are tracked. The present model addresses processes which are likely to be anticipated processes. The model was applied to several scenarios of the total system (Wilson et al., 1994; Andrews et al., 1994). See Section 5.3.10.

Subactivity 1.5.3.1.2 - Separate scenarios into anticipated and unanticipated categories. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.5.3.1.3 - Development of parameters describing the scenarios. Information pertaining to this subactivity is provided under Subactivity 1.5.3.1.1.

Subactivity 1.5.3.1.4 - Determine adequacy of design envelope of waste package. Information pertaining to this subactivity is provided under Subactivity 1.5.3.1.1.

Forecast: A preliminary list and description will be developed of anticipated features, processes, and events which may have to be considered in analyzing the substantially complete containment requirement. Model development for the features, processes, and events will continue. See the forecast for Section 5.3.8.

5.3.5 Activity 1.5.3.2 - Develop Geochemical Speciation and Reaction Model

Subactivity 1.5.3.2.1 - Develop data base for geochemical modeling. A GEMBOCHS "anonymous" account was established to permit off-site users to obtain data files for use with EQ3/6 and GEMBOCHS. The account's initial inventory includes the R22 suite of EQ3/6 data files and element catalogs for Tc, Th, U, Np, Am, and Pu.

In the JEWEL code development, several routines were revised, and GEMBOCHS data files based on bulk composition now contain only the species which appear in the dependent dissociation reactions for aqueous species, minerals, and gases. An improved algorithm was developed and incorporated for selecting and printing literature references. FACET code development incorporated routines that permit users to add new literature references; these routines also ensure that all requisite information pertaining to such additional references is obtained from the user. The GEMBOCHS/JEWEL/FACET update that permits multiple data references for species contained in the SUPCRT92 data base was completed.

The first edition of the new, stand-alone GEMBOCHS Data Catalog for the YMP Technical Data Base was generated. This quarterly catalog includes an overview of the GEMBOCHS system, a discussion of recent accomplishments, and tables summarizing the

types of thermodynamic data contained in GEMBOCHS, the specific chemical species and data contained in the thermodynamic data files, and the literature sources for these data.

The first draft of a new Individual Software Plan for the GEMBOCHS software library was completed; this Individual Software Plan supersedes earlier Individual Software Plans written for GNGBOCHS, FACET, and JEWEL. Work began on incorporating the CHEMVAL 5.0 and the NIST data bases into GEMBOCHS.

The United States contribution to the Nuclear Energy Agency Technical Volume on Americium was completed. A review of the document and verification that the original authors followed the indicated procedures in the selection and evaluation of thermodynamic data was completed. Americium compounds and complexes were submitted for inclusion in GEMBOCHS. The Nuclear Energy Agency Technical Volume on Plutonium is being compiled.

Subactivity 1.5.3.2.2 - Develop geochemical modeling code. The independent verification and validation activity for EQ3/6 Version 7 was completed. A baseline review was conducted to document its suitability for quality affecting work. Only minor defects were found in Version 7.2a. These defects did not adversely impact the suitability of the software for certification, and Version 7.2a was certified. The minor defects are being corrected, and will be issued as part of a Version 7.2b release.

Work is continuing on EQ3/6 Version 8.0. Two additional capabilities are being added: (1) a generic ion-exchange model and (2) correction of supporting data, mostly thermodynamic, to pressures off the 101.3 kPa-steam saturation curve. Work on Version 8.0 included necessary developments in the data file preprocessor and development of the data file formats. In addition to including new types of data for pressure corrections, a more flexible approach is being implemented to represent temperature dependence of the thermodynamic data, thereby allowing some available thermodynamic data to be brought on-line.

Work progressed on incorporating thermodynamic pressure corrections and a generic ion exchange model. The test case library is being enlarged to represent these new capabilities, as well as the new redox disequilibrium capability. A preliminary round of regression testing comparing Version 8.0 with Version 7.2a was conducted. A convergence problem exists in high concentration solutions and is still being diagnosed. In addition, the major option switches in EQ3NR and EQ6 have been made common between the two codes to make them easier to use.

Forecast: The final draft Nuclear Energy Agency plutonium volume is expected to be complete in December 1994.

5.3.6 Activity 1.5.3.3 - Generate Models for Release From Spent Fuel

Subactivity 1.5.3.3.1 - Generate release for spent fuel models. Several approaches to dissolution modeling have been explored, including different model forms, as well as full and partial regressions that depend on some assumptions about the degree of variable dependency. Classical rate laws are being examined. Such rate laws are usually applied to homogeneous gas or liquid reactions. Additional terms are needed to account for liquid-solid reactions and any radiation effects.

A simple dissolution rate equation was developed for UO_2. The spent fuel data are not adequately represented this equation because of the complex dependence on oxygen concentration. A preliminary conjecture is that the dependence is caused by radiolysis. Unfortunately, the equations cannot be used to make comparisons because of their different forms. However, it is possible to make direct comparisons between the UO_2 and spent fuel data. The surface areas of both the spent fuel and UO_2 powder specimens were carefully measured using the Brunauer, Emmett and Teller method. An important aspect of the Brunauer, Emmett and Teller measurement on the spent fuel specimens was that the specimens consisted of batches of separated grains (Gray and Thomas, 1993). Grain separation is crucial because the surface area that is contacted by water must be adequately represented by a Brunauer, Emmett and Teller measurement.

The empirical modeling effort to fit the existing UO_2 dissolution data was expanded to include models having solid-liquid interfaces and chemical potential terms. Portions of these phenomenological models can be derived from nonequilibrium thermodynamics and classical representations of solid-liquid boundaries. At the present stage, this model development is preliminary and provides only functional forms. In addition to the above dissolution rate model for the intrinsic dissolution rate for grain volumes, work on grain boundary, grain volume and fragment geometry effects on dissolution/release rate is also being extended (Stout et al., 1990). The extension was motivated by observations from unsaturated spent fuel testing. The unsaturated testing is performed with pellet fragments, and recent observations show that outer surface grains spall from the fragments. To address spent fuel degradation during the dissolution/release process, additional terms can be added to the model.

Forecast: Expansion of the dissolution model to include solid-liquid interface and chemical potential terms will continue. Semi-empirical modeling of spent fuel oxidation will continue.

5.3.7 Activity 1.5.3.4 - Generate Models for Release From Glass Waste Forms

Subactivity 1.5.3.4.1 - Generate release models for glass waste forms. An activity plan is being written for this activity.

Forecast: The existing glass waste form degradation model will be simplified and restructured for incorporation into the YMIM Engineered Barrier System Performance Assessment code.

5.3.8 Activity 1.5.3.5 - Waste Package Performance Assessment Model Development

As a supplement to Total System Performance Assessment - 1993, RIP 3.13 and YMIM 2.0 were used to evaluate the containment and control of release provided by various waste package designs (CRWMS M&O, 1994j).

Twelve RIP calculations were performed to determine the effects of different corrosion rates. For each of three thermal loads, calculations were run with corrosion rates as specified in Total System Performance Assessment - 1993 and with half that corrosion rate. For each of these, calculations were run with an inner barrier that fails quickly and an inner barrier that fails 1000 years after the outer barrier.

Predictions of compliance with the substantially complete containment requirement are sensitive to the assumptions about corrosion. None of the calculations predicted container failures during the first 300 years. Only two calculations showed failures at 1000 years, but in those the number of failures was substantial. Therefore, if the current models for corrosion and failure are accurate, achievement of substantially complete containment is strongly dependent on corrosion rate. The addition of a 1000-year inner barrier provides only a modest decrease in the mean normalized release over 10,000 years, but decreasing the corrosion rate of the outer barrier provides a more substantial increase. The intermediate thermal load allowed the largest releases.

To simulate the effect of changing the pitting resistance of the inner barrier, YMIM calculations of containment life were performed. The calculations use Lamont's model for pitting failure of the inner barrier (CRWMS M&O, 1994k). The calculations produce a narrow distribution of failures. Different values of the parameters for the pitting model were used to simulate the affects of choosing different alloys for the inner barrier. For reasonable parameter values, pitting lifetimes for the corrosion-resistant barrier varied from a few hundred years to over a million years. The life of the barrier is therefore strongly dependent on its pitting resistance. A large part of the variation in barrier lifetime is due to the temperature dependence of pit growth. At long times, the decreasing temperature results in very small pit propagation rates.

Subactivity 1.5.3.5.1 - Development of system model. The PANDORA waste package performance code (O'Connell et al., 1993) was applied to the sensitivity analysis on releases from the waste package (O'Connell et al., 1994); see Section 5.3.9. The YMIM code (Lamont, in prep.) was developed and applied to Total System Performance Assessment - 1993 and to the sensitivity analysis. See Section 5.3.10 for the applications. Temperature-dependent effects were the focus for model enhancements for use in Total System Performance Assessment - 1993.

The YMIM code was adapted as a FORTRAN-callable subroutine and integrated (Lewis and Wilson, 1994) into the SNL Total System Analyzer code. The algorithms of YMIM for container history and source term were transmitted to the M&O for their adaptation and use in Total System Performance Assessment - 1993. The stand-alone YMIM code has been installed at LLNL.

YMIM and PANDORA have complementary approaches, although in the future they will be merged. YMIM covers a broad scope of near-field and Engineered Barrier System processes using summary submodels, with the purpose of examining model interconnections and the impact on other outputs of various submodel assumptions. PANDORA focuses on processes of water-waste form contact inside the waste package and on mobilization and release rates from these processes.

Diffusive transport of radionuclides away from the waste package may be important in the absence of substantial seepage flow. Diffusion through one or two zones, corresponding to backfill and the nearby host rock, has been modeled (Ueng and O'Connell, 1992; Ueng and O'Connell, 1994). The diffusion code will also be merged with YMIM.

A preliminary draft of a document that is part of the software configuration management series for the AREST-CT computer code has been prepared (PNL, in prep.). The Design Description document describes the design to be implemented for new models. The focus of the upgrade is to ensure that the detailed waste package model accounts for the principal processes affecting container degradation, waste form alteration, and radionuclide release into the host rock. The code will be used to perform analyses at the process model level to determine the sensitivity of the radionuclide source term to various near-field parameters. The code will be used to quantify the radionuclide source term for analyses with codes such as RIP and YMIM.

Subactivity 1.5.3.5.2 - Development of uncertainty methodology. No progress during the reporting period, this was an unfunded activity.

Subactivity 1.5.3.5.3 - Water flow into and out of a breached container. No progress during the reporting period; this was an unfunded activity.

Forecast: YMIM will be enhanced in preparation for preliminary analyses for technical site suitability. The enhancements will include merging of submodels from PANDORA and the two-zone diffusion model, and other enhancements as may be determined by the scenario identification (see Section 5.3.4) and the performance requirements. YMIM qualification will start in accordance with the YMIM Individual Software Plan.

5.3.9 Activity 1.5.4.1 - Deterministic Calculation of Releases from the Waste Package

A sensitivity study using PANDORA used different base cases within the range of feasible design and environment parameter values (O'Connell et al., 1994). Variations about these base cases determined sensitive parameters in these cases. The PANDORA model concentrates on only a few processes, but the range of release-rate time history shapes and of sensitive parameters is extensive. Release rate is sensitive to different combinations of near-field hydrology, design, and waste form/geochemistry interaction parameters.

Forecast: See Section 5.3.10.

5.3.10 Activity 1.5.4.2 - Probabilistic Calculation of Releases from the Waste Package

This activity is currently in the prototype and planning stage. The revised Scientific Investigation Plan for waste package performance assessment has been approved for interim use and has been submitted to YMSCO. Improved waste package models were developed, and release calculations were performed in support of Total System Performance Assessment - 1993 as described above.

YMIM (see Section 5.3.8) has been used in the Total System Performance Assessment - 1993 (Wilson, 1994) and in two uncertainty studies. In the Total System Performance Assessment - 1993, YMIM is a subroutine and calculates the source term. The inputs to the overall system, including the Engineered Barrier System subsystem, are treated probabilistically by selecting many input data sets randomly. YMIM tracked the time-varying rock temperature and the effects on ground-water flow and on container, cladding, and waste form responses. The resulting radionuclide releases were used in the far-field transport analysis.

A study on the impact of uncertainties in the input parameters (Gansemer and Lamont, 1994) was performed by varying key parameters, for four Engineered Barrier System design alternatives. Much of this variation in the parameters is due to limited knowledge rather than to known variability. The results of this preliminary analysis indicate that resolving the uncertainties about radionuclide solubilities, temperature, water return time, and cladding creep failure could be important for selecting the Engineered Barrier System design. The four design alternatives combine emplacement and areal power density alternatives.

A second statistical study used the input and output parameter sample from the Total System Performance Assessment - 1993 (Wilson et al., 1994) in which YMIM was embedded as the source term model. The same four design alternatives were analyzed in the Total System Performance Assessment - 1993. The analysis identified the parameters whose variability induces most of the variability in the output performance. Differences in design-performance variability are correlated with key parameters, pointing to the particular processes important in each case.

Forecast: Analyses of the Engineered Barrier System/near-field environment subsystem will be carried out to support the preliminary technical site suitability assessment. Analyses will also be performed to support an assessment of substantially complete containment and controlled release. A value-of-information study will be performed using results of Total System Performance Assessment - 1993 and additional Engineered Barrier System/near-field environment subsystem analyses. The study will use sensitivity/uncertainty methods, and the results will be used to guide priorities in additional data acquisition and model enhancement activities.

5.3.11 Activity 1.5.5.1 - Determine Radionuclide Transport Parameters

Subactivity 1.5.5.1.1 - Radionuclide distribution in tuff wafers. Work in this area that is also pertinent to determining the radionuclide distribution in tuff cores is reported under Subactivity 1.5.5.1.2. No significant activity occurred during the reporting period pertaining exclusively to distributions of radionuclides in tuff wafers.

Subactivity 1.5.5.1.2 - Radionuclide distribution in tuff cores. The core-flow apparatus was reassembled in a new glove box and in a new laboratory. Temperature and pressure controls were tested. Interfacing to the data acquisition computer remains to be done. A new core sample was prepared for installation, and core porosity was determined.

One objective of this subactivity is to measure the rate of exchange diffusion in clinoptilolite of important radionuclides. Clinoptilolite is one of the major sorptive minerals in the tuffs at Yucca Mountain. For slow advective transport or rapid adsorption, local equilibrium holds. For slow adsorption or rapid fluid flow, kinetics must be taken into account. Sorption by clinoptilolite occurs predominantly by cation exchange. The rate limiting process in cation exchange is the diffusion of the cation to the exchange site. For large crystals or for cations whose size approaches that of the intracrystalline channels (e.g., UO_2^{++} and NpO_2^{++}), diffusion could limit the attainment of equilibrium. The results of diffusion experiments will be used to assess the need for diffusion modeling when predicting radionuclide transport.

The extent of cation exchange is strongly dependent on the crystallographic face exposed to the aqueous solution (Burns et al., 1992). Exchangeable cations in clinoptilolite are located in channels that lie in the *a–c* crystallographic plane. Because these channels do not intersect the prominent (010) plane, diffusion through that crystal face will be negligible. Diffusion and exchange equilibrium will be most rapid for (001), (100), and other edge faces that intersect the *a–c* plane.

Large single crystals of clinoptilolite from Succor Creek, Oregon, were hand picked from vugs. To obtain homoionic species, clinoptilolite crystals were placed in solutions of different salts and allowed to diffuse/exchange. Crystal faces were identified. The crystals were mounted for electron microprobe and secondary ion mass spectroscopy analysis, exposing the relevant crystallographic face.

Preliminary analysis of treated crystals was done by electron microprobe. Average values for the composition indicate that exchange was far from complete and/or polishing the surface after the salt treatment removed the homoionic zone. Crystals were also analyzed by secondary ion mass spectroscopy depth profiling. Very preliminary results confirm the non-homoionic nature of these crystals and indicate that variations in elemental concentrations of the exchange cations are significant within 2 μm of the surface. There is a distinct difference in the variation with depth of the alkali cations for the (010) and edge faces. In the former, alkalis are depleted near the surface; in the latter, alkalis are enhanced very close to the surface.

Efforts are proceeding to produce homoionic crystals. When these are obtained, the radionuclide diffusion experiment will proceed, entailing the placing of individual crystals already mounted for electron microprobe and secondary ion mass spectroscopy into solutions of Cs, Sr, U, and Np. Each homoionic species will undergo exchange with each of the four radionuclide solutions.

Forecast: The core flow experiment protocol will be documented. Reports on colloid characterization, radionuclide diffusion in clinoptilolite, and transport of soluble species will be produced.

5.4 CHARACTERISTICS AND CONFIGURATIONS OF THE WASTE PACKAGES (SCP SECTION 8.3.4.3)

No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

5.5 WASTE PACKAGE PRODUCTION TECHNOLOGIES (SCP SECTION 8.3.4.4)

5.5.1 Design Activity 4.3.1.1 - Waste Package Fabrication Process Development

Efforts on production technologies focused on filler material.

5.5.2 Design Activity 4.3.1.2 - Waste Package Closure Process Development

Efforts on production technologies focused on filler material.

5.5.3 Design Activity 4.3.1.3 - Waste Package Closure Inspection Development

Efforts on production technologies focused on filler material.

5.5.4 Design Activity 4.3.1.4 - Remote In-Service-Inspection Development

Efforts on production technologies focused on filler material.

5.5.5 Design Activity 4.3.1.5 - Internal Filler Material Process Development

Addition of filler material may improve criticality control and long-term isolation. Preliminary results of both thermal investigations and neutronics investigations utilizing graded iron shot filler have been reported (CRWMS M&O, 1994h).

Use of waste package filler materials may assist in (1) controlling criticality by displacing moderator in the event of repository flooding, (2) sorbing radionuclides in the event of water intrusion into the waste package, (3) providing cathodic protection in the event of water intrusion into the waste package, (4) inhibiting movement (collapse) of other materials inside the waste package, and (5) increasing thermal conductance and reducing fuel rod temperatures. However, use of filler material would significantly increase waste package weight and cost.

Neutronics and thermal investigations were performed for iron shot filler in a 21 pressurized-water reactor assembly multi-purpose canister with multibarrier disposal container. The 21 pressurized-water reactor assembly waste package has a higher thermal output and higher criticality potential than any of the other waste packages. By itself, this means of moderator displacement does not achieve the needed level of control for fresh fuel, so other criticality control measures would be needed such as adoption of burnup credit, or credit for supplemental neutron absorber materials.

Thermal investigations of the effect of iron shot filler material indicate that waste package internal thermal conductance may be increased. Unfortunately, the thermal conductivity of bulk iron shot is very poorly known.

These preliminary results indicate that iron shot should be considered as a filler material. After the physical properties are better defined, detailed evaluations can be performed to better quantify filler material worth.

Forecast: Work on closure process development and closure inspection development will resume in FY 1995.

5.6 WASTE PACKAGE PERFORMANCE (SCP SECTION 8.3.5.9)

5.6.1 Activity 1.4.1.1 - Integrate Design and Materials Information (Metal Container)

The initial Engineered Materials Characteristics Report was begun and is expected to be published during the next reporting period. A container materials workshop was held; see Section 5.1.4 for a description.

An evaluation of the draft survey of iron-based corrosion-allowance materials indicates that the compiled data do not meet the waste package design requirements. Additional work is being considered.

An evaluation of a draft scientific investigation plan on metal barriers indicates that it should be revised to emphasize the current multibarrier design concepts. An alternative testing approach, based on recommendations from the container materials workshop (described in Section 5.1.4), was suggested. The scientific investigation plan will be revised as needed.

Subactivity 1.4.1.1.1 - Mechanical properties. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.1.2 - Microstructural properties. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.1.3 - Physical properties. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.1.4 - State of stress in the container. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.1.5 - Characterization and inspection of weld integrity. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.1.6 - Characterization of the container surface. No progress during the reporting period; this was an unfunded activity.

Forecast: A technical requirements document for closure and inspection methods will be issued during the next reporting period.

5.6.2 Activity 1.4.1.2 - Integrate Design and Materials Information (Alternate Barriers Investigation)

The purpose of the nonmetallic barriers task is to characterize the behavior of nonmetallic materials, such as ceramics, and to determine degradation rates and mechanisms. One of the barriers of the disposal container may be fabricated from a nonmetallic material. A primary objective of this task is determination of the feasibility of making a nonmetallic barrier as part of a waste package.

Subactivity 1.4.1.2.1 - Survey of alternative barrier designs, materials, and processes to determine feasibility of fabricating a satisfactory waste package. Site conditions may be too aggressive for the metal alloys under consideration, or performance assessment may predict metal container degradation rates that are inconsistent with substantially complete containment. If lifetimes of metal containers are considered inadequate, alternative materials with superior corrosion resistance will be chosen.

A survey of nonmetallic barrier material capabilities was conducted. The results are an amalgam of opinions and general beliefs held in the ceramic industry. The survey presents some ceramic material selection criteria, alternatives for the materials which might be used, and potential fabrication methods. This includes free-standing ceramic components and ceramic coatings/linings for metallic structures. For various reasons, many companies were not interested in the production of ceramic waste containers; however, a small group of companies showed enthusiasm for the concept.

The survey concludes that it will be possible to fabricate ceramic or ceramic-metal nuclear waste containers by any of several currently available techniques, and using any of several ceramic materials. Even so, a minimum of three (and more likely five or six) years development time will be required to learn to reliably fabricate such large structures. Dense aluminum oxide currently offers the most attractive combination of cost, thermal conductivity, chemical resistance, strength and manufacturability. High alumina, vitreous bonded ceramics would be less expensive than completely crystalline, sintered ceramics and may prove to be almost as durable. Thermal conductivity may be the limiting factor in their use. Closure techniques for extremely large ceramic containers are as yet unproven, especially since this task must be accomplished remotely in a hot cell. Experimental verification of appropriate properties will be required to determine which of the available techniques can be used in this context.

Because of their brittle nature, ceramics will probably be used in conjunction with metals. Two approaches are worth additional study. The first is to produce self-supporting, impervious ceramic liners for a metallic shell using cold isostatic pressed, green machined blocks that would then be sintered and diffusion bonded. Closure would be accomplished mechanically, in conjunction with a thermal sprayed outer coating to develop an acceptable seal. Metallizations and brazes could be used but will limit credit for performance. The second approach is to thermal spray coat a metal container with a relatively thin, dense ceramic layer that should prevent it from corroding under repository conditions. Magnesium aluminate spinel offers most of the benefits of alumina and is not subject to thermal transformation. This type of construction probably poses the least overall risk of failure. Modern thermal spray techniques could also allow the fabrication of free-standing containers or coating ceramic waste containers using a single basic process and may allow a seamless final closure.

Subactivity 1.4.1.2.2. - Mechanical properties. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.2.3. - Microstructural properties. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.2.4 - Thermophysical properties. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.1.2.5 - Nondestructive characterization of the alternate barrier investigations waste package container. No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

5.6.3 Activity 1.4.2.1 - Selection of the Container Material for the License Application Design

Subactivity 1.4.2.1.1 - Establishment of selection criteria and their weighting factors. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.1.2 - Material selection. Metal barrier material candidates were selected as part of the Controlled Design Assumptions document using an expert panel. Testing and analysis will focus on these materials (see Section 5.6.8)

Forecast: No activity is planned for FY 1995.

5.6.4 Activity 1.4.2.2 - Degradation Modes Affecting Candidate Copper-Based Container Materials

No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

5.6.5 Activity 1.4.2.3 - Degradation Modes Affecting Candidate Austenitic Materials

Austenitic materials are part of the test matrix reported in Activity 1.4.2.4.

Subactivity 1.4.2.3.1 - Assessment of degradation modes in austenitic container. No progress during the reporting period; this was an unfunded activity. Related discussion is included under Section 5.6.6, Subactivity 1.4.2.4.3.

Subactivities 1.4.2.3.2 through 1.4.2.3.9. No progress during the reporting period; these were unfunded activities. The single exception is the inclusion of stainless steels in the test matrix for stress corrosion cracking (see Section 5.6.6, Subactivity 1.4.2.4.4).

Forecast: No activity is planned for FY 1995.

5.6.6 Activity 1.4.2.4 - Degradation Modes Affecting Ceramic-Metal, Bimetallic/Single Metal, or Coatings and Filler Systems

Subactivity 1.4.2.4.1 - Assessment of degradation modes affecting ceramic-metal systems. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.4.2 - Laboratory test plan for ceramic-metal systems of the alternate barriers investigations. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.4.3 - Assessment of degradation modes affecting bimetallic/single metal systems. Conclusions from Bullen (in prep.) are that the low temperature oxidation (nonaqueous) of carbon steels and other iron-base materials results in negligible wastage for credible temperatures (< 300°C) of the outer barrier of the waste package. In aqueous environments, for pH values of approximately 5 to 11, the corrosion rate depends on the oxygen content in water. Temperature plays an important role since it affects the kinetics of oxygen diffusion to the iron or steel surface and affects the solubility of oxygen in the water. A maximum corrosion rate is reached at around 80°C. Alloy content and microstructure do not have a major effect on the corrosion rate. Oxidizing species such as nitrate are expected to add to the corrosion rate. At pH values greater than 11, carbon steel and other ferrous metals self-passivate, and the corrosion rate typically drops to very small values. The quality and integrity of the passive layer determine the corrosion behavior. Use of concrete or grout can conceivably condition water to alkaline pH values. At pH values less than 5, the alloy content and the microstructure play a major role. The corrosion rate increases exponentially as the pH decreases; carbon steel and other ferrous materials would degrade quickly if the pH falls to around 4 or less. Certain kinds of microorganisms can produce acid pH values, as can decomposition and pyrolysis of man-made materials.

Subactivity 1.4.2.4.4 - Laboratory test plan for bimetallic/single metal material systems. The purpose of this subactivity is to conduct a comprehensive corrosion test program, the data from which is needed to establish substantially complete containment and controlled release rate predictions for the waste packages to meet regulations. The compliance with regulations will be determined using Total System Performance Assessments, which will rely on the subsystem models incorporating the data developed by this effort. The corrosion program contains testing to assist in the selection of waste package candidate materials, in the selection of materials from among the candidates for waste package design, and to provide samples for early characterization to be included in the Engineered Barrier System field tests.

In preparation for the planning anticipated for the Program Approach to begin in the FY 1995-1996 time frame, a comprehensive workshop was held to outline the corrosion test program (discussed in Section 5.1.4). A cost estimate was prepared detailing the test specimen procurement and laboratory installation. It was estimated that several thousand specimens could be required for the long term (five-year) Integrated Corrosion Test; although, statistical analyses are continuing to reduce the scope of the estimated number of samples required, without compromising the integrity of the test. Four bounding environments were identified that encompass the range a metal barrier could experience. These environments are: a dilute ground water, a concentrated ground water, an acidified concentrated ground water, and, an alkalized concentrated ground water. It is planned to conduct the tests at 60°C and 90°C, in both the liquid and vapor phases (a few samples will be exposed at the liquid-vapor interface).

The thermogravimetric analysis tests continued on a number of candidate alloys. These tests are being conducted to determine under which temperature, humidity, and surface conditions, corrosion initiates on a suite of alloys. These data will be used to determine the propensity for waste package surface electrochemical activity, in terms of the conditions required to maintain a continuous water film on metal surfaces, and whether as a result,

corrosion will be a factor for any given alloy. The objective of further tests is to obtain a more detailed mapping of the adsorption and condensation behavior of water on various materials as a function of water partial pressure and temperature. Exploratory tests were performed on commercially pure copper (UNS C10200). The corrosion product varied between slight orange-brown discoloration to exfoliating black corrosion product. Under all test conditions, there were significant regions of the test specimen where visual inspection indicated very little oxidation. The most severe corrosion occurred at the bottom of the specimen. It appears that the enhanced corrosion at the bottom of the specimen is due to water accumulation there. Exploratory tests were also performed on a carbon steel (UNS G10200) and a high-nickel alloy (UNS N08825).

The purpose of the crack growth tests is to evaluate the stress corrosion cracking response in Yucca Mountain saturated zone water environments (testing in more severe environments will be performed at a later date). Stress corrosion is an important degradation mode that can affect both the corrosion allowance and corrosion resistant materials. Work to date has only been performed on the corrosion resistant alloys: Alloy 825 (UNS NO8825), and, Types 304L and 316L stainless steels (UNS S30403 and UNS S31603); the stainless steels are being tested to provide baseline information. After approximately 3.5 years of testing of these three materials in simulated UE-25 J#13 water at 90°C, no environmental cracking has initiated. A mathematical model prediction of lifetime using these results would indicate that these materials should undergo at least several thousand years of repository exposure without stress corrosion cracking. Continuation of these tests beyond five years without the initiation of an environmental crack growth event would indicate a lifetime in excess of 10,000 years under similar exposure conditions. An Activity Plan for similar testing using different samples representing the other candidate alloys has been prepared and approved. These tests will be started next period.

The pitting corrosion tests are being performed to provide experimental input to the corrosion model development to predict pitting initiation and propagation rates. These tests use electrochemical techniques to determine localized corrosion phenomena, including critical values of potential, pH, temperature, chloride ion concentration, and concentration of other ionic species. A literature review was performed to identify experimental techniques for localized corrosion, initially focusing on aqueous pitting corrosion. The pitting corrosion experimental techniques reviewed to date were categorized based on the types of quantities they can measure.

Experimental techniques have been developed to monitor corrosion phenomena (pH, corrosion potential, temperature) in the Large Block Test experiment. Corrosion coupons and crevice samples have been ordered, representing all of the candidate waste package materials. Electrochemical polarization measurements are planned for selected container materials to provide benchmarks for designing in situ sensors. During the Large Block Test and eventually the in situ tests in the Exploratory Studies Facility, the parameters to be measured include the exchange current density, the equilibrium potential, and the cathodic and anodic Tafel constants.

Forecast: The Integrated Corrosion Facility will be installed and testing initiated, the thermogravimetric analysis testing will continue, the modeling and electrochemical testing to support the pitting corrosion studies will continue, the crack growth testing will continue, and the Large Block Test corrosion testing activity will be initiated.

Subactivity 1.4.2.4.5 - Assessment of degradation modes in coatings and filler systems. No progress during the reporting period; this was an unfunded activity.

Subactivity 1.4.2.4.6 - Laboratory test plan for coatings and filler systems of the alternate barriers investigations. No progress during the reporting period; this was an unfunded activity.

Forecast: Stress corrosion cracking testing will continue, pitting corrosion testing will begin, and air/steam thermogravimetric analysis testing will continue.

5.6.7 Activity 1.4.3.1 - Models for Copper and Copper Alloy Degradation

No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

5.6.8 Activity 1.4.3.2 - Models for Austenitic Material Degradation

Subactivities 1.4.3.2.1 through 1.4.3.2.5. No progress during the reporting period; these were unfunded activities.

Subactivity 1.4.3.2.6 - Pitting, crevice, and other localized attack. The purpose of model development is prediction of long-term performance of container materials. As a first step, modeling has focused on pitting of a corrosion resistant barrier. An important aspect of pitting is its stochastic nature. Much of the modeling work is aimed at developing the stochastic aspect of pitting.

The pitting potential is the electrochemical potential below which pits will not form on the surface of a metal exposed to a given environment. However, under potentiostatic conditions, its value depends upon how long one waits to observe whether a pit appears, so an investigation of the dependence of the pitting potential on "wait time" began using the Pit Initiation and Growth Stochastic model. The new simulations were to determine if a threshold was reached in pitting potential as the wait time increased. No threshold was observed. These results may imply either that there is no thermodynamic threshold in pitting potential for real materials or that the Pit Initiation and Growth Stochastic model breaks down at low potentials. Careful experiments are required to determine which of these conclusions is correct.

The effect of the number of individual runs in a simulation on the computed pitting potential was investigated. There appears to be an effect of "sample size" on the results from the stochastic model. Further calculations were aimed at exploring the effects of a decaying birth probability. A pitting potential or a "true" thermodynamic threshold is predicted.

Potentiodynamic measurements of the pitting potential were also simulated. As discussed by Shibata and Takeyama (1977; 1980), the stochastic theory of pitting predicts that the pitting potential is actually a distributed quantity. They deduced the most probable value of the pitting potential as a function of sweep velocity. Linear and exponential relationships between the birth probability and the applied potential result in a dependence of the most probable pitting potential on the square root and logarithm of sweep velocity, respectively. Since the Pit Initiation and Growth Stochastic model computes the generation of a stable pit using the concepts of embryo death and a critical embryo age in addition to embryo birth, the relationships are more complex than those assumed by Shibata and Takeyama (1977; 1980).

Numerical experiments used the exponential dependence of birth probability on the applied potential. Results show that the Pit Initiation and Growth Stochastic model predicts more complex behavior than a simple analytical model for the case in which the birth probability depends exponentially upon the applied potential. For a relatively mild exponential dependence of birth probability the expected logarithmic behavior is exhibited only over a limited range of sweep velocity. For a more severe exponential relationship, bilinear behavior is exhibited on the logarithmic plot. The deviation from simple logarithmic behavior is related to the effects of embryo death prior to their reaching the critical age.

Subactivities 1.4.3.2.7 and 1.4.3.2.8. No progress during the reporting period; this was an unfunded activity.

Forecast: Pitting corrosion modeling will continue.

5.6.9 Activity 1.4.3.3 - Models for Degradation of Ceramic-Metal, Bimetallic/Single Metal, and Coatings and Filler Alternative Systems

No progress during the reporting period; this was an unfunded activity.

Forecast: Work on this activity will begin during FY 1995.

5.6.10 Activity 1.4.4.1 - Estimates of the Rates and Mechanisms of Container Degradation in the Repository Environment for Anticipated and Unanticipated Processes and Events, and Calculation of Container Failure Rate as a Function of Time

YMIM includes a models for pitting corrosion, aqueous general corrosion, air oxidation, and early and random failures. The application of YMIM in making predictions that are relevant to this section are discussed in Sections 5.3.4 and 5.3.8.

Forecast: See Section 5.3.10.

5.6.11 Activity 1.4.5.1 - Determination of Whether the Substantially Complete Containment Requirement is Satisfied

No progress during this reporting period; this was an unfunded activity.

Forecast: See Section 5.3.10.

5.6.12 Activity 1.5.5.2 - Radionuclide Transport Modeling in the Near-Field Waste Package Environment

No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

CHAPTER 6 - PERFORMANCE ASSESSMENT

Performance assessment is the set of activities needed for quantitative evaluations of repository system performance to evaluate the suitability of a site to assess compliance with regulations, and to support the development of a geologic repository. Performance assessment conducts investigations and develops models to examine the performance of the Mined Geologic Disposal System in the preclosure and postclosure phases through the use of total system and subsystem assessments. Performance assessment verifies, benchmarks, and documents computer codes for assessing the performance of the system's overall waste isolation.

6.1 WASTE RETRIEVABILITY (SCP SECTION 8.3.5.2)

Site Characterization Plan Section 8.3.5.2, Waste Retrievability, addresses the issue: Can the repository be designed, constructed, operated, closed, and decommissioned so that the option of waste retrieval will be preserved as required by 10 CFR 60.111?

A systems study report (CRWMS M&O, 1994m) was written to address the advantages and disadvantages of longer retrievability periods. In doing so, an understanding of the repository operations was necessary. This input was obtained through the design groups currently working on the Advanced Conceptual Design of the repository. Once this concept was understood, it was determined that the normal retrieval operations would be the reverse of emplacement.

Advantages cited in the report for keeping the repository open longer were increased confidence in system performance, ability to recover valuable natural resources, and increased public confidence in the repository to isolate waste. The disadvantages were cost and safety.

Although the performance confirmation program is not currently defined, the study evaluated this area and found that 50 years is most likely sufficient for testing most anticipated processes. However, there is a nonquantifiable advantage in the added potential to observe the unforeseen evolution of the environment or waste package degradation processes.

Retrieval scenarios were developed that addressed waste package problems, site problems, and retrieval for recovery. Both normal and abnormal conditions were considered; however, abnormal conditions were based on engineering judgment rather than analysis.

The Site Characterization Plan in this section discusses similar subject matter. Functions are listed that the repository must perform: provide access to the emplacement boreholes; provide access to waste packages; remove waste packages from the emplacement borehole; and transport and deliver the waste packages to the surface facilities. The assumption used in the Site Characterization Plan was vertical storage of small waste packages. The current assumption is to use multi-purpose canisters in in-drift emplacement mode. Thus, the functions listed above would not be applicable to today's Program Approach.

Although the systems study report does not track each issue verbatim, the study does address a significant portion of this Site Characterization Plan section, and does represent technical and scientific work on a scoping level.

- **Forecast:** No activity is planned for FY 1995.

6.2 PUBLIC RADIOLOGICAL EXPOSURE - NORMAL CONDITIONS (SCP SECTION 8.3.5.3)

No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.3 WORKER RADIOLOGICAL SAFETY - NORMAL CONDITIONS (SCP SECTION 8.3.5.4)

A copy of, and site license for, the coupled neutron - gamma ray radiation transport code MCNP has been ordered from the Radiation Shielding Information Center at Oak Ridge National Laboratory. Representatives from the performance assessment group have attended the initial MCNP training sessions held at Los Alamos. This code will provide the performance assessment group with the capability to perform the radiation shielding calculations necessary to quantify direct radiation exposure to workers during facility operations.

Although primarily procured to assess worker radiological exposures, the MCNP code will also be used to allow the performance assessment group to independently assess the waste container design for criticality during both the pre- and postclosure phases of the repository.

Forecast: The MCNP code will be installed on two 486 IBM-compatible personal computers. A series of test problems supplied with the code will be set up and executed to demonstrate dose prediction capabilities.

6.4 ACCIDENTAL RADIOLOGICAL RELEASE (SCP SECTION 8.3.5.5)

A preliminary probabilistic risk assessment was developed for accidental radionuclide releases initiated by either a rockfall or waste transporter accident under conditions derived in part from the current Exploratory Studies Facility design and its assumed role in a potential repository. The results of this preliminary assessment are currently undergoing review, and are expected to be used, in part, for establishing methodology for analytical classification of items important to radiological safety in accordance with 10 CFR 60.2 (see Section 2.3.2).

Meteorological data gathered at five sites in the vicinity of Yucca Mountain over the past eight years have been reviewed and analyzed. The analysis conducted was in accordance with the guidelines published by the NRC for the determination of atmospheric dispersion coefficients to be used in the vicinity of a nuclear reactor to assess the potential ionizing radiation dose to members of the public.

Work has started on modeling and calculating of the deformation induced in the waste container due to impulse loading resulting from rockfall and other energetic events. The goal of the work is to develop a relatively simple mechanical model that allows rapid container evaluation to postulated energetic encounters. The accuracy of the model results developed will be compared to those from three-dimensional mechanical response codes.

Forecast: A mechanical model for predicting the deformation of waste containers will be developed. The model will be developed to be valid in both the elastic and plastic regions of the constitutive material stress/strain response.

The reduced meteorological data from five Yucca Mountain monitoring sites will be consolidated into an interpolation routine to allow rapid predictions of dispersion factor probabilities at the restricted boundary for a ventilation exhaust stack at an arbitrary (i.e., as yet undetermined) location at the proposed repository.

6.5 GROUND-WATER TRAVEL TIME (SCP SECTION 8.3.5.12)

The DOE developed an approach to calculation of ground-water travel to evaluate compliance with 10 CFR 60.113(a)(2) and to evaluate compliance with the ground-water travel time disqualifying condition in DOE's general siting criteria (10 CFR Part 960). The approach was presented to the NWTRB (in April and in more detail in September). The DOE submitted a written description of the approach to NRC, and NRC generally agreed with the approach, but indicated they would closely monitor DOE progress during the development of the approach (see Chapter 2, Section 2.2.2.2, Issue Resolution, for more detail).

6.5.1 Activity 1.6.2.1 - Model Development

Calculational models for ground-water travel time must address the initiation and propagation of ground-water flow along fast pathways to the accessible environment. The initial stages of the model development activities have investigated the conditions that might lead to initiation of these fast paths. In addition, some of the details concerning how the results of the calculations will be interpreted have also been studied.

Subactivity 1.6.2.1.1 - Development of a theoretical framework for calculational models. The essence of the approach is that pre-waste-emplacement ground-water travel time is considered to be a distribution that defines the likelihood of water particles reaching the accessible environment at a specific time. This distribution is a distribution of water particle transport times (i.e., radionuclide transport times in which the effects of chemical retardation

are neglected). It is affected by particle starting locations which, in the unsaturated zone, are dependent on the lateral and vertical extent of the disturbed zone, and by particle ending locations at the accessible environment. It is also affected by dispersion and matrix diffusion because water particle transport will proceed along different flow paths through both the heterogeneous rock matrix and fractures. The approach therefore takes into account the transport processes of dispersion and matrix diffusion.

Further, the approach includes the evaluation of the significance of permanent changes in the chemical and physical properties of the controlled area and subsequent definition of the disturbed zone boundary. It then involves the development of separate distributions for water particle transport from the boundary of the disturbed zone through the unsaturated zone and, in the saturated zone, from points below the repository horizon to the accessible environment. The approach also includes conducting sensitivity analyses to evaluate and provide the basis for taking into account the effects of uncertainty in hydraulic properties, boundary conditions, alternate conceptual flow models, matrix diffusion, and dispersion on the distributions of water particle transport times. Finally, it includes the convolution of the resultant distributions in the unsaturated and saturated zones and the evaluation of the significance of short transport times (i.e., those less than 1,000 years, that may be included in the resultant distribution, in terms of their effect on the performance of the system as a whole). Because of the complexity of the calculations the approach is iterative, and it is expected that two iterations will be performed prior to the DOE determination of technical site suitability.

Subactivity 1.6.2.1.2 - Development of calculational models. Ground-water travel time calculations must be consistent with all site data which include geochemical and isotopic data. The data being collected by DOE will be incorporated into the calculational approach as a check of the numerical results.

A particle tracker animation program was enhanced to display porosity and flow vectors. Use of this program allows visualization of computational results, which can be used to identify difficulties in data or software. The particle tracker is written in the PV-WAVE command language also used to generate color plots of hydrologic units and porosities of various cross-sections of Yucca Mountain.

Forecast: No activity is planned for FY 1995.

6.5.2 Activity 1.6.2.2 - Verification and Validation

Laboratory-scale and field-scale studies have been progressing in order to obtain process-level information appropriate for verifying and validating numerical representations of natural processes used in ground-water travel time and Total System Performance Assessment calculations.

Subactivity 1.6.2.2.1 - Verification of codes.

Near-field thermohydrologic analyses

A near-field thermohydrologic model was developed to evaluate the heat transport and fluid flow occurring in the vicinity of heat-generating waste packages placed within a backfilled drift. This problem setup was used to benchmark the performance of two computational codes, TOUGH2 and FEHM, in predicting temperatures and saturations in the near-field. Detailed comparisons of thermal and saturation results from several simulations at various time levels indicated excellent agreement between the predictions of two codes. Previous analyses of near-field heat and fluid flow, which were used as input to the Total System Performance Assessment - 1993 (Andrews et al., 1994; Wilson et al., 1994), were based on a conduction-only model of near-field heat flow, and a far-field model for hydrothermal processes. Results from the current analyses have indicated two major differences from previous results: (1) predictions of waste package surface temperatures are much lower than corresponding conduction-only model results due to vapor-phase heat transport, and (2) liquid saturations near the waste package are significantly lower than the average saturations predicted with repository-scale models due to the capillary barrier effects of the backfill. These studies thus provide a first attempt of detailed process-level modeling of heat and fluid flow at the waste package/drift scale, which was identified as one of the key areas of uncertainty in Total System Performance Assessment - 1993. These results have been utilized in a "mini-Total System Performance Assessment" to evaluate the significance of the near-field thermohydrology on releases from the Engineered Barrier System and to the accessible environment.

Hydrothermal Code Comparisons

In a continuation of work reported in Progress Report #10 (DOE, 1994c), the TOUGH2 code was used to investigate possible dryout in the vicinity of a potential nuclear waste repository and the perching of water above the repository as a function of time after waste emplacement. Two parametric studies were conducted to supplement the fracture aperture calculations. In the first study, the effect of material properties on repository dryout were computed and indicated that both the material properties and infiltration rate significantly affect dryout. Results of the second study show that dryout is significantly reduced as the rate of ground water infiltration increases. In addition, the use of temperature isotherms based strictly on conduction solutions appreciably overpredicts the extent of repository dryout.

Forecast: Future work in FY 1995 will focus on the use of the near-field thermohydrologic models for a variety of thermal management, repository layout, and thermohydrologic material properties to better define the temperature, saturation, and humidity fields in the vicinity of the waste packages for incorporation into Total System Performance Assessment - 1995.

Subactivity 1.6.2.2.2 - Validation of models. Project representatives attended the Site Evaluation and Design of Experiments Core Group meeting in Harwell, United Kingdom, April 13-14, 1994. The mandate of the Core Group is to provide guidance to the Nuclear

Energy Agency/Organization for Economic Cooperation and Development Coordinate Group in evaluating the effectiveness of the Site Evaluation and Design of Experiments Advisory Group in supporting the Radioactive Waste Management Committee and the national program objectives of the participating countries. The Core Group prepares a document outlining the proposed activities for consideration by the Site Evaluation and Design of Experiments members. The topic of the September Site Evaluation and Design of Experiments meeting in Paris, France, is "The Validation of Geosphere Models." The proposal is for a Performance Assessment Advisory Group/Site Evaluation and Design of Experiments project to cooperatively plan and demonstrate the evaluation of alternative conceptual models using "critical experiments." A conceptual model can be described as a system of theories or hypotheses. A critical experiment is one which gives a result consistent with one hypothesis and inconsistent with another. A methodology for identifying the crucial aspect or hypothesis that differentiates the various conceptual models and the designing of an experiment to test that hypothesis will be developed by an NAS and Organization for Economic Cooperation and Development committee during the upcoming year. The new Performance Assessment Advisory Group/Site Evaluation and Design of Experiments initiative will employ and evaluate the methodology for advancing performance assessments of geologic repositories. This initiative comes at the conclusion of INTRAVAL and as a result of the lessons learned from INTRAVAL.

The Core Group recommended that Performance Assessment Advisory Group and Site Evaluation and Design of Experiments form a joint working group on the validation of geosphere models. The topic is of major importance and involves the expertise of the members from both advisory groups. The recommendation is in response to the Performance Assessment Advisory Group Core Group recommendation that the two groups discuss validation issues to provide a broad framework for further discussion with the Performance Assessment Advisory Group. The Site Evaluation and Design of Experiments Core Group considers the topic of validation to be an obvious subject to enhance the cooperation and information flow between the Performance Assessment Advisory Group and the Site Evaluation and Design of Experiments.

The Site Evaluation and Design of Experiments Core Group recommended that the Coordinating Group consider forming a new Hypothesis Testing Working Group. This topic is one of the three major focus areas of the Site Evaluation and Design of Experiments Coordinating Group. The Working Group would concentrate on the design and implementation of experiments to test the validity of hypotheses and possibly provide an interface between the NAS study on hypothesis testing (NAS, 1983) and the Nuclear Energy Agency.

The Natural Analogue Working Group of the Commission of the European Communities held a workshop in Santa Fe, New Mexico, September 11-15, 1994, which was attended by YMSCO international programs, site characterization, and performance assessment staff members. The presentations at this workshop included updates on natural analogue work around the globe. The YMSCO contributed a discussion of its current work in the Taupo Volcanic Zone (New Zealand) and Cigar Lake (Canada). The workshop was followed by a field trip to the Nopal I Natural Analogue Site in the Peña Blanca Range near

Chihuahua, Mexico. The NRC is funding characterization work at this location and is interested in having an agreement within which DOE supplements their work with well-defined, discrete characterization and modeling activities.

As noted by Miller et al. (1994), the United States high-level waste disposal concept differs significantly from the disposal concepts being considered in other nations' programs in that it involves disposal in the unsaturated zone. Therefore, there is an effort being made to find analogue sites, such as the Taupo Volcanic Zone, that allow study of processes in analogous rock types and unsaturated conditions. In an NRC-sponsored survey of potential geochemical analogues by Pearcy and Murphy (1991), the Peña Blanca, Mexico, site was described as one potentially useful analogue. The Peña Blanca site is being studied under NRC sponsorship. It is a hydrothermal uranium ore deposit in unsaturated rhyolitic ignimbrites and allows the study of the migration of material from almost completely oxidized ore. A deliberately conservative and preliminary estimate of UO_2 oxidation rate limits was made by Pearcy et al. (1993) of the Center for Nuclear Waste Regulatory Analysis. The estimate was based on observations of uraninite transformation and assumptions about how long one of the Peña Blanca deposits has been above the water table. The rates suggested by the data and assumptions about Peña Blanca geologic history were similar to those obtained in the laboratory by Grambow et al. (1990). At the Natural Analogue Working Group Workshop, in the discussion of the potential value of the Nopal I uranium deposit at Peña Blanca, it was suggested that the actual dissolution rate of this oxidized uranium body is perhaps one part in ten-million per year. Further work is needed to refine this type of estimate. There is also evidence for fracture flow and transport and for matrix diffusion at the site that invites further study and quantification.

Pearcy and Murphy (1991) suggested that uranium occurrences in volcanic rocks in Nevada would be less directly comparable analogues than Peña Blanca. However, Castor and Henry (1993) argue that although Peña Blanca is an excellent analogue for Yucca Mountain, it does not have the zeolites and smectite minerals thought to play a potentially significant role in delaying radionuclide transport at Yucca Mountain. Castor and Henry, on behalf of the Nevada Bureau of Mines and Geology, submitted a proposal to YMSCO to study a number of uranium mineralizations in volcanic host rocks in Nevada and Oregon. It is anticipated that the survey of potential sites accompanying the proposal will be narrowed through analyses of a more complete survey of the available data. Some of these sites may be studied, through exploration and testing, especially in the confirmation phase of the high-level waste disposal program, during construction, operation, and prior to final closure. The confirmation phase is prescribed by regulation (10 CFR Part 60), and is to include a program of field and laboratory studies to provide "Performance Confirmation" information to be included in the license amendments required to receive and emplace waste and for final closure. The idea is to select analogue sites that potentially can supply data for different and mutually exclusive parameters and processes. For processes particularly vital to performance, such as the interaction of unsaturated zone flux and geochemistry, it may be useful to study several analogues that allow a rough response surface to be constructed that can then be compared with similar response surfaces created through modeling. This could assist in building confidence in performance assessment model applications to very long times.

Forecast: The YMSCO will continue to support the performance assessment Advisory Group and Site Evaluation and Design of Experiments in FY 1995. The United States is a member of the Organization for Economic Cooperation and Development and supports the Nuclear Energy Agency. The Nuclear Energy Agency is one organization that facilitates the involvement of the international scientific/technical community in the formation of approaches to specific aspects of repository performance assessment. The DOE/Environmental Restoration and Waste Management and DOE/OCRWM participation in the Performance Assessment Advisory Group and Site Evaluation and Design of Experiments, which advise the Radioactive Waste Management Committee in terms of technical issues that should be addressed using Nuclear Energy Agency resources would be beneficial to DOE.

Flow and Transport Through Single Fractures

Significant progress has been made on the development of laboratory techniques for characterization of relative permeability of discrete fractures. Results of these fracture-relative permeability experiments were presented at the 1994 High-Level Waste Conference (Nicholl and Glass, 1994). In addition, refinement of methodologies for replicating natural fractures and measurement of fracture aperture structure continued. Two sets of frames for the fracture containment cell were fabricated. Techniques for the implementation of boundary conditions directly within the replica fracture were developed.

Work on a field tracer test in support of the Large Block Test at the Fran Ridge test site was initiated. An adsorptive tracer (FD&C Blue #1 food coloring) was introduced to the fracture system through ponded infiltration at three sites within the annular excavation surrounding the block test location. Material surrounding the block was then excavated in the form of horizontal benches at approximately 0.5-m vertical intervals. At each bench level, the three infiltration sites are mapped using a grid located over the infiltration site. Fracture traces are recorded, along with spatial distribution of the tracer. Depending on the specific site, between seven and eleven levels have been mapped to date.

Fracture-Matrix Interaction

Comparison of physical experimentation and numerical simulation of matrix imbibition from a flowing fracture into Topopah Spring Tuff was presented at the 1994 High-Level Waste Conference (Glass et al., 1994). This work was a collaborative effort in which SNL ran fracture-matrix interaction experiments using x-ray imaging and USGS made hydraulic property measurements on the same tuff slabs.

An integrative effort was established with the ultimate goal of abstracting process-level work on single fractures and fracture/matrix interaction into performance assessment modeling at intermediate, site, and total system levels.

In follow-on activities, two large format (0.6 m x 0.3 m) fracture-matrix interaction experiments were performed. The experiments were conducted to investigate the behavior of matrix imbibition from a vertically oriented, saturated slot fracture. In the first study, the principal axes of the heterogeneity structure were oriented differently for the two slabs used

in the test. Distinct differences in the transient saturation fields were noted between the two slabs. In the second test, dry slot fractures were located 15 cm on either side of the flowing fracture. These dry fractures were noted to function as capillary barriers to the imbibing water. Current efforts are focusing on digitizing and analyzing the x-ray images.

Effective Media Property Scaling in Heterogeneous Systems

Work to provide an experimental basis for scaling relationships for hydraulic properties in tuff continued. Multiscale gas permeability measurements were collected from the Fran Ridge tuff block and a second face of the Tiva Caprock block. Analysis of the collected data shows distinct differences in the scaling behavior measured on the two rock samples. These differences in the upscaling behavior are believed to be related to the heterogeneity structure of the rock samples and have been independently quantified using light imaging techniques.

The theory governing upscaling by simple volume averaging was reviewed and implemented. Algorithms predicated on volume averaging upscaling have been developed both for one- and three-dimensional cases. Measured scaling behavior has been compared to that predicted by the volume average model, and the two cases tested thus far have yielded similar results. Such comparisons are useful in determining when more sophisticated models might be required to predict scaling behavior. It should also be noted that these volume averaging algorithms are important for performance assessment calculations for upscaling additive properties such as porosity and bulk density (Tidwell, 1994).

Conduct Nonisothermal Flow Model Development and Validation

Results of nonisothermal experiments in a two-dimensional test cell and corresponding numerical analyses were presented at the 1994 High-Level Waste Conference (Ho et al., 1994).

Follow-on experimental work using a light imaging method to investigate liquid saturation distributions was inhibited by leaks in the apparatus. Repeated attempts to seal the leaks were only temporarily effective. As a result, a new test chamber was designed to alleviate the problems occurring in the original test cell. In addition, based on the results of the first set of nonisothermal experiments, plans were made to design experiments in tuff to observe the possible mechanisms of dryout, condensation caps, and refluxing.

Results of numerical analyses of nonisothermal laboratory experiments are described in a report (Sobolik et al., in prep.), as well as two other nonisothermal experiments. The purpose of the report is to detail thermohydrologic processes that may be relevant to Yucca Mountain and to demonstrate the capability of TOUGH2 in modeling thermohydrologic processes.

Develop/Validate Reactive Transport Model - Conduct Integrated Transport Experiment

The objective of this activity is to demonstrate a framework for the validation of reactive transport models in saturated and unsaturated porous and fractured media by

conducting intermediate-scale integrated transport experiments. The main focus of work during the second half of FY 1994 was completion of a joint caisson experiment.

Two LiBr and one $NiCl_2$ pulses were eluted from the caisson. Over 1000 water samples were taken during the course of the experiment. Analysis of the samples for Li and Br were initiated and analysis of Ni concentrations in the same samples began. Preliminary analysis of the data indicates that Ni breakthrough occurred earlier than anticipated; for this reason post-mortem examination of the sand will be important.

Final material characterization experiments associated with the caisson were completed in preparation for a possible caisson post-mortem. Results indicated that Li adsorbs irreversibly onto Wedron sand. Additional experiments and review of the literature revealed that one probable substrate in the sand, kaolinite, does irreversibly adsorb Li. Studies of reversibility of Ni adsorption onto Wedron indicated that Ni desorbs only slowly at pH 5 and higher; after 41 h at pH 5.1, 20 percent of the available Ni remained adsorbed. Data from Ni-Li exchange experiments on Wedron 510 sand at pH 7.6 to 7.9 suggest that Li concentrations on the order of 10 ppm are required to detectably decrease the fraction of Ni adsorbed onto the sand for total Ni concentrations up to 1 ppm.

Three studies of Li and Ni transport in lab-scale columns of Wedron sand were performed to evaluate the applicability of batch sorption data to lab-scale and caisson-scale transport studies. These included an unsaturated 30 cm column with a 1 ppm Li concentration pulse; a saturated 10 cm column with a 200 ppb Ni pulse; and a 10 cm saturated column with a pulse containing a 10 ppm Li, 200 ppb Ni mixture. A saturated column LiBr transport experiment was completed and modeled using the CXTFIT code. Li and Br transport parameters obtained in the saturated laboratory column were used to successfully model breakthrough curves from the actual caisson sample data.

Develop/Validate Retardation Model for Performance Assessment

Under this work, the retardation models used in total systems performance assessment will be evaluated and improved. Experiments were conducted to evaluate the predictive ability of alternate models that could be used in performance assessment to describe retardation due to sorption. Several scenarios were evaluated in which simple geochemical models may not be adequate to describe radionuclide transport at Yucca Mountain. This information will be used to develop probability density functions for K_ds for future total systems performance assessments, and will provide input to geostatistical models for K_ds at Yucca Mountain.

Development of a Method to Measure Sorption Under Unsaturated Conditions

Efforts to develop a method to measure sorption of uranium under unsaturated conditions were completed. A final report (Ward and Siegel, in prep.) describing progress in several areas of research was transmitted to the Project Office. Areas examined included: applications of Turbula mixer techniques to uranium sorption measurements, the use of uranium isotopic differentiation to measure sorption under unsaturated conditions,

development of a technique for quantitative uranium measurements in unsaturated sands using laser-induced fluorescence, and potential development of a fiber optic sensor for in situ pH measurements.

Performance Assessment-Process-Level Integration

Efforts in support of the performance assessment process level integration task were conducted. These included evaluation of data bases of thermodynamic constants, mineralogy and sorption data for Yucca Mountain to determine the feasibility of applications of several methods to represent retardation in the next Total System Performance Assessment. Yucca Mountain mineralogical data have been incorporated into a data base. A total of 1187 matrix and 185 fracture samples have been entered into the file. The data are derived from 15 boreholes from various locations at the mountain. Thirty-one minerals are grouped into 11 mineral groups based on similar sorption properties. The data are normalized and sorted according to Total System Performance Assessment - 1993 hydrostratigraphy for the development of a three-dimensional geostatistical mineralogical model of the mountain.

An initial geostatistical model for mineralogy within the welded unit of the Topopah Spring was formulated. The spatial correlation displayed by five mineral classes in the TSw is difficult to discern due to a lack of sufficient data. The data exhibit a high degree of variability within each of the mineral classes. Although two of the three horizontal semivariograms were fit with nugget values equal to zero, it is likely that a significant nugget effect exists. It was concluded that, at present, there are not enough boreholes at a close enough spacing to define this nugget effect. Similar to the horizontal variograms, spatial correlation is difficult to discern in the vertical direction. Only two of the vertical variograms could be fit with models and both of these display large ratios of nugget value to sill value. It appears that the variability within the mineral groups is high. Techniques for correcting this variability may include a rethinking of the way in which the mineral classes are defined.

Alternative formulations of retardation factors that could be used to bound the significance of transport of radionuclides by colloids on the results of Total System Performance Assessment calculations were examined. These included a modified retardation factor that includes the effects of reversible formation of radioactive colloids and an inverse method to identify conditions under which irreversible formation of colloids could significantly increase radionuclide discharges.

Development of Models for Sorption by Mineral Mixtures: Ni Adsorption on End-Member Components of Wedron 510 Sand

Previous efforts have shown that the sand used in the caisson experiment (Wedron 510 sand) contains several mineralogical components that are potentially important contributors to its aggregate surface chemistry and adsorption of Ni. Specifically, quartz, Fe-oxyhydroxide, kaolinite, and Ca-Mg carbonate were identified. Ni adsorption measurements were reported for the raw sand under both CO_2-free conditions and conditions of partial equilibration with air, and for synthetic goethite and quartz (Min-U-Sil 5) under CO_2-free conditions. Based on the goethite data, a tentative model was proposed in which Ni adsorption onto the raw sand

was accounted for by Fe-oxyhydroxides that effectively covered 50 percent to 80 percent of the surface of the sand.

Additional Ni adsorption measurements were made on acid-washed sand and goethite under both CO_2-free and atmospheric conditions, and on kaolinite and Min-U-Sil 5 quartz under atmospheric conditions only. These data, in combination with results from a study of competition between Ni and Li for adsorption sites, allow us to propose a more refined and realistic model of the surface chemistry of Wedron 510 sand, in which kaolinite as well as Fe-oxyhydroxides is important, with a negligible role played by quartz and Ca-Mg carbonate.

Forecast: Subject to FY 1995 funding allocations, planned activities address issues related to the suitability of current treatments for discrete fracture flow and fracture/matrix interaction. Limited understanding of the physical processes requires that these issues be addressed through physical observations in the laboratory and the field combined with systematic, process based numerical experimentation. Information obtained in this task will also be of crucial importance to other participants in evaluating bounding continuum descriptions of flow in fractured porous media. This investigative effort will be coordinated with performance assessment development activities to produce strategies for incorporation of physical processes into models used to evaluate Technical Site Suitability, ground-water travel time in particular.

The primary focus of work in FY 1995 will be processes controlling flow in discrete fractures, fracture networks, and fracture-matrix interactions. These processes are very important to the analysis of ground-water travel time. This work includes several related components.

Physical and numerical investigation of discrete fracture pressure-saturation and permeability-saturation relations will continue. These investigations provide critical information on the nature of two-phase flow in unsaturated fractures required for simplified models for use in the estimation of ground-water travel time. Specifically, physical experiments will be conducted in analog fractures (casts of natural tuff fractures, controlled property analog fractures), and numerical experiments will focus on the development and validation of models that incorporate critical physics lacking in current conceptual models for two-phase flow in fractures.

Work to characterize physical geometry and relative permeability of fractures collected at Fran Ridge as part of the FY 1994 fracture network infiltration field study associated with the Large Block Test. These data will be used in other activities.

Field data obtained from the infiltration experiment at Fran Ridge will be analyzed to provide supporting information for the Large Block Test and to feed development of alternative conceptual models of ground-water travel time. Specifically, this activity will (1) interpret fracture maps and spatial distribution of tracer, and (2) identify flow processes consistent with observed behavior.

Evaluation of the influence of matrix imbibition on fracture percolation to provide information crucial for the development of alternative conceptual models of ground-water travel time will continue. Specifically, this activity will (1) conduct experiments in tuff slabs with vertically oriented fractures to evaluate the effects of matrix anisotropy, ability of fractures to act as capillary barriers, and fracture characteristics on matrix imbibition and solute diffusion within the matrix; (2) characterize hydraulic properties of tuff slabs and fractures used in the experiments; and (3) perform numerical simulation to challenge conceptual models and evaluate media characterization needs.

Nonisothermal flow experiments will focus on conducting a series of numerical simulations to aid in the design of future experimental systems, drawing in part on the isothermal experiments conducted in FY 1995. Numerical simulations will address such concerns as the size of the experiment, process scaling, appropriate boundary conditions, and necessary material properties.

Physical experimentation of property scaling by measuring permeability with the automated gas permeameter system at multiple measurement scales will continue. Experiments will be conducted on tuff blocks collected from Yucca Mountain including bedded tuffs, fractured and nonfractured tuffs. Efforts will also be made to model the measured scaling behavior and compare to relevant upscaling theory.

6.5.3 Activity 1.6.3.1 - Analysis of Unsaturated Flow System

Subactivity 1.6.3.1.1 - Unsaturated zone flow analysis. The Probabilistic Systems Assessment Group met in Paris, France, in June 1994 and was attended by a staff member from Pacific National Laboratory representing YMSCO. Representatives from eleven countries attended the meeting. The Probabilistic Systems Assessment Group is sponsored by the Organization for Economic Cooperation and Development, Nuclear Energy Agency, in Paris, France. The Probabilistic Systems Assessment Group investigates the use of probabilistic approaches to assessing the performance of a nuclear waste disposal site. The YMSCO contributed to technical discussions about statistical techniques and problem solution methods. Contributions were also made in the presentation and discussion of the new benchmarking exercises.

The meeting was divided into three categories: (1) progress on code intercomparisons by Probabilistic Systems Assessment Group participants, (2) a topical session on "Philosophy and Methodology of Probabilistic Systems Assessment and Allied Techniques," and (3) a topical session on "Experience of Application of Probabilistic Systems Assessment in National Programs."

Presently, the one code intercomparison in progress was a benchmarking problem for an entire repository system, based on data taken from the Waste Isolation Pilot Plant site in New Mexico. The major purpose of the exercise was to determine the uncertainty due to different conceptual models based on a complete set of site data. The comparison showed that the results (expressed either as release of radionuclides or dose) can vary over orders of

magnitude, even using the same data set. Some of the results "clumped" nicely, but all were from groups that did not explicitly model the ground-water movement. Results from all participants were due in July, and the report was published in the fall.

The Performance Assessment Advisory Group has recommended to the Nuclear Energy Agency that the Probabilistic Systems Assessment Group be disbanded, and on that recommendation this was the final meeting of the group.

The M&O represented YMSCO at the Organization for Economic Cooperation and Development/Nuclear Energy Agency workshop of models of radionuclide binding by natural organic substances (e.g., humic and fulvic acids) September 14-16, 1994, in Bad Zurzach, Switzerland. This workshop was attended by an international group of scientists from countries including Switzerland, Germany, France, the United Kingdom, Belgium, Italy, Sweden, Denmark, Spain, Japan, Norway, Canada, Finland, and the United States. This diverse group of scientists encompassed specialists in the experimental study, modeling, field study, and performance assessment of the interaction of aqueous radionuclides and natural organic materials. Presentations included performance assessment of the impact of natural organic materials on radionuclide transport at potential repository sites, recent experimental studies of complexing of radionuclides by natural organic materials and its competition with other complexing agents, field-based studies of natural organic materials and techniques to extract and characterize natural organic materials, and modeling of the binding of radionuclides to natural organic materials in aqueous systems. The models presented ranged from process-level mechanistic models to generalized bounding models directed toward performance assessment issues.

Forecast: See Section 6.5.2, Subactivity 1.6.2.2.2 - Validation of models, Support of International Programs.

One-Dimensional Infiltration Analyses with a Semi-Analytic Model

This preliminary study investigated the impact of uncertain parameters on predictions of the state of the ambient unsaturated hydrologic system. A one-dimensional column was set up to describe a heterogeneous layered system representative of the unsaturated zone at Yucca Mountain. Monte Carlo simulation was employed to propagate the uncertainty in input parameters into uncertainty in predictions of saturation profiles, using a semi-analytic model of steady-state Darcy flow in the unsaturated zone. Results from this study have provided useful insight regarding the definition of effective properties for use in deterministic simulations. The ranking of hydrologic properties according to their sensitivity also helps provides input into a strategy for calibrating multidimensional site-scale models.

INTRAVAL

INTRAVAL test cases were used as input for flow calculations as reported by Robey (in prep.).

Forecast: Work in FY 1995 will focus on evaluating the impact of parametric, conceptual model and numerical model uncertainties on geosphere (unsaturated zone) performance using sensitivity analysis techniques. Conceptual model alternatives include treatment of fracture flow and faults, description of recharge, and climate effects. Parametric issues include matrix and fracture hydrologic properties, fracture geometry and continuity, net infiltration rate, and boundary/initial conditions. Numerical issues include model dimensionality and grid sensitivity. These will be carried out using the three-dimensional site-scale model being developed at Lawrence Berkeley Laboratory, and will be used to describe the unsaturated flow pathways for incorporation into Total System Performance Assessment - 1995.

Subactivity 1.6.3.1.2 - Saturated zone flow analysis. A presentation was given to the NWTRB April 11-12, 1994, on "The Role of the Saturated Zone in Waste Isolation." This presentation summarized some of the saturated-zone modeling work that contributed to Total System Performance Assessment - 1993.

Forecast: No activity is planned for FY 1995.

6.5.4 Activity 1.6.4.1 - Calculation of Pre-Waste-Emplacement Ground-Water Travel Time

Subactivity 1.6.4.1.1 - Performance allocation for Issue 1.6. No progress during the reporting period; this was an out-year activity.

Subactivity 1.6.4.1.2 - Sensitivity and uncertainty analyses of ground-water travel time. No progress during the reporting period; this was an out-year activity.

Subactivity 1.6.4.1.3 - Determination of the pre-waste-emplacement ground-water travel time. No progress during the reporting period; this was an out-year activity.

Forecast: An initial ground-water travel time estimate will be calculated in FY 1995 using techniques described under Subactivities 1.6.2.1.1 and 1.6.2.1.2.

6.5.5 Activity 1.6.5.1 - Ground-Water Travel Time After Repository Construction and Waste Emplacement

No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.5.6 Activity 1.6.5.2 - Definition of the Disturbed Zone

No progress during the reporting period; this was an out-year activity.

Forecast: Project participants will hold expert elicitations to determine the bounds of the volume of the disturbed zone. These estimates will be incorporated into the calculational models of ground-water travel time described in Subactivities 1.6.2.1.1 and 1.6.2.1.2.

6.6 TOTAL SYSTEM PERFORMANCE (SCP SECTION 8.3.5.13)

The Executive Summary for the SNL contribution to Total System Performance Assessment - 1993 (Wilson et al., 1994) was completed and published with the report in May 1994. The objectives, approach, assumptions, and results of the Total System Performance Assessment - 1993 iteration was presented to NRC staff in a DOE-NRC Technical Exchange in September 1994.

Efforts continued to define frameworks for effective and efficient integration of experimental and process-level modeling work into performance assessment work. Integration of the data from process-level work into realistic performance assessments will require significant investigation of coupling among the processes, as well as accounting for changes in scale between relatively homogeneous laboratory systems and the heterogeneous systems expected to exist in actual geological structures. Ongoing laboratory and field experiments are providing useful and important information on aqueous flow through fractures, scaling effects, nonisothermal effects, and site geochemistry. The integration work will also provide closer ties between Total System Performance Assessment and site characterization work, and will provide guidance on the type of data required and when more data are needed.

Mini-Total System Performance Assessments

Several analyses were completed to update and enhance the performance assessments performed during the second iteration of Total System Performance Assessment - 1993. These new analyses address specific issues raised during and following the completion of Total System Performance Assessment - 1993, and serve as precursors for the more complete analyses to be conducted during FY 1995.

The mini-Total System Performance Assessment analyses are the first to address release from the Engineered Barrier System and the impact of uncertain conceptual models of waste package degradation and radionuclide mobilization on the peak Engineered Barrier System release. In addition, these analyses are the first to incorporate drift-scale thermohydrologic analyses and humidity-initiated aqueous corrosion on cumulative release and dose. These analyses have been documented in a draft report to YMSCO (CRWMS M&O, 1994n).

Flow in Discrete Fractures

A number of experimental results are currently available, and modeling tools exist to describe flow in discrete fractures in relatively small geometries (meter scale). To abstract these tools to Total System Performance Assessment scale, it is imperative to examine experimental and modeling interfaces at scales ranging from a few meters to intermediate lengths (tens of meters) to mountain distances. This work is being done as a collaborative

effort involving both Total System Performance Assessment personnel and process-modeling personnel. Numerical simulations of fracture flow were performed on an intermediate block scale. The equivalent continuum, dual porosity, and dual permeability models are being compared during simulations of water imbibition into three representations of a fractured system. Fracture map data of a large block at Fran Ridge have been provided for future use in modeling at the intermediate-block scale.

Heterogeneity and Scaling

Development of appropriate scaling methods and techniques to account for heterogeneity in Yucca Mountain strata is imperative to the generation of proper abstract models of the mountain for use in flow analyses. Some experimental results and meter-scale models have been developed for materials representative of Yucca Mountain. The experimental results are based on gas permeation measurements at various aperture sizes, and the corresponding models attempt to relate the experimental results to geostatistical analyses. In a collaborative effort involving Total System Performance Assessment and process-level personnel, methods are being examined to develop scaling abstractions to mountain scale. A statistical analysis to corroborate the one-dimensional scaling formula used in Total System Performance Assessment - 1993 was completed with good agreement between scaling of the standard deviation of probability distributions for porosity. A literature search concerning the available techniques of upscaling hydrologic properties was conducted, and the results will be used to determine the optimum techniques for upscaling hydrologic properties from the core-plug scale to the model grid-bloc scale. Laboratory data on permeability from an air permeameter over a range of lab scales were obtained to help in the development of scaling curves to allow scaling from lab to geostatistical scale.

Nonisothermal Flow Modeling

Experimental studies and sub-meter-scale modeling have shown significant thermal effects on flow patterns in water-saturated porous media. Since it is possible that a potential repository at Yucca Mountain would be at high temperature for many years, it appears that Total System Performance Assessment of the potential repository should address thermal effects. The integration activity in nonisothermal flow modeling is an effort to develop the link between experiments and process-level models and the mountain-scale models that must be used for Total System Performance Assessment. As an initial modeling effort related to nonisothermal flow phenomena, an evaluation of the G-Tunnel heater tests (Johnstone et al., 1985) was conducted. Johnstone's experiments showed that a large amount of in situ water migrated toward the heater hole as a result of extended heating of the partially-saturated rock surrounding the kilowatt heater. Analyses of three studies were conducted: laboratory heater tests in saturated and partially saturated sand, heater tests in crushed tuffaceous rock, and heater experiments performed in G-Tunnel. Preliminary results of the analyses serve to address issues related to building confidence in the codes that will eventually be used to assess performance of the potential repository. A formal report on results obtained thus far has been drafted for submission to YMSCO (Sobolik et al., in prep.).

Geochemical Retardation

A considerable background of laboratory-scale or meter-scale experimental data and models on geochemical retardation are available. However, a need remains for methods to abstract the process-scale geochemical results to total system performance assessment scales. This need is particularly strong in the area of colloid transport, where little Total System Performance Assessment work has been done for Yucca Mountain. A literature review was conducted of colloid-formation and colloid-transport models. One colloid-transport model and perhaps a second model were found to be of sufficient level-of-detail as to be acceptable for Total System Performance Assessment calculations. The first model describes the case where radionuclides can reversibly adsorb onto colloids. The second model involves irreversible sorption onto colloids. In addition, development has continued on the geochemical transport code LEHGC. An informal report on results is in preparation for submittal to YMSCO.

Forecast: Subject to FY 1995 funding allocations, the integrated Process-Level/ Performance Assessment efforts that began in FY 1994 will continue in an attempt to define frameworks for effective and efficient integration of experimental and process-level modeling work into performance assessment work. Strategies will be developed to incorporate and abstract process-level work on heterogeneity and scaling into performance assessment calculations and into development of techniques for calculation of ground-water travel time. In order to improve the robustness of abstracted models currently being assumed and/or used in total system assessments, detailed process modeling will be performed to develop and test abstractions of such processes as: (1) waste package corrosion initiation criteria and corrosion models, (2) drift/waste package-scale thermal hydrology, (3) waste form alteration/dissolution, (4) Engineered Barrier System diffusive transport, and (5) aqueous flow and radionuclide transport in fractured/porous unsaturated rock.

Efforts will be initiated to begin development of Total System Performance Assessment - 1995, and will include the conduct of sensitivity studies using preliminary information from process-level models from fracture-matrix interactions, reactive transport, nonisothermal flow, and scaling.

An assessment will be made of the potential effects of coupling rock mechanical behavior with thermal-hydrologic influences. Large-scale calculations indicate there is potential for significant mountain uplift due to waste emplacement; therefore, the need to understand how the mechanical behavior of the rock will influence performance assessment predictions is essential. The importance of the mechanical coupling will be assessed studying relatively simple systems in which the flow can be computed using standard codes and then compared to computations in which the mechanical behavior is calculated.

Analyses will be performed that will assist in identifying critical data types required from the Calico Hills characterization program. The analyses include transport coupling, flow coupling, and flow analyses.

Input to the Total System Performance Assessment data set will continue, using the hydrogeologic data currently available from various sources, to ensure that data are available in a format required for use in performance assessment models.

6.6.1 Performance Assessment Activity 1.1.2.1 - Preliminary Identification of Potentially Significant Release Scenario Classes

Subactivity 1.1.2.1.1 - Preliminary identification of potentially significant sequences of events and processes at the Yucca Mountain repository site. The National Energy Agency convened a working group chartered with developing an international data base that contains features, events, and processes of potential importance for long-term safety of nuclear waste repositories. The working group selected a ToolBooK template in which the data should be entered. It was discovered that this program was inadequate for applications on Yucca Mountain, so two relational data bases are being used in parallel. A total of 148 features, events, and processes including those on the list from the Site Characterization Plan was entered into the data bases.

Subactivity 1.1.2.1.2 - Preliminary identification of potentially significant release scenario classes. As a result of comment resolution reported last period on a report by Barr (in prep.), a considerable rewrite ensued, which includes a section on unresolved issues important to scenario screening. The nominal-flow scenarios presented in this report are significant to site characterization and licensing because the scenarios, which represent detailed analyses, can be used as bases for further site-performance modeling.

Forecast: A short list of nominal flow scenarios will be developed to describe the expected behavior of flow and transport in the mountain. The scenarios will be selected from Barr (in prep.) and used as a baseline for initial performance calculations, and later, for comparison with other scenarios.

Scenarios will be constructed for tectonic processes at Yucca Mountain.

6.6.2 Performance Assessment Activity 1.1.2.2 - Final Selection of Significant Release Scenario Classes to be Used in Licensing Assessments

No progress during the repository period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.6.3 Performance Assessment Activity 1.1.3.1 - Development of Mathematical Models of the Scenario Classes

Subactivity 1.1.3.1.1 - Development of models for releases along the water pathways. Results from a Case Study using INTRAVAL (conducted in FY 1993) were documented (Robey, in prep.) and submitted to YMSCO for policy review.

Subactivity 1.1.3.1.2 - Development of a model for gas-phase releases. No progress during the repository period; this was an out-year activity.

Subactivity 1.1.3.1.3 - Development of a model of releases through basaltic volcanism. No progress during the repository period; this was an out-year activity.

Subactivity 1.1.3.1.4 - Development of a model of releases through human intrusion. No progress during the repository period; this was an out-year activity.

Forecast: Subject to FY 1995 funding allocations, a subsystem model for tectonics will be developed from currently available information, including USGS studies and Electric Power Research Institute expert elicitations. Probabilities of location, magnitude, recurrence rates, and effects of seismic events will be assessed.

6.6.4 Performance Assessment Activity 1.1.4.1 - The Screening of Potentially Significant Scenario Classes Against the Criterion of Relative Consequences

No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.6.5 Performance Assessment Activity 1.1.4.2 - The Provision of Simplified, Computationally Efficient Models of the Final Scenario Classes Representing the Significant Processes and Events Mentioned in Proposed 10 CFR 60.112 and 60.115

No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.6.6 Performance Assessment Activity 1.1.5.1 - Calculation of an Empirical Complementary Cumulative Distribution Function

No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.7 INDIVIDUAL PROTECTION (SCP SECTION 8.3.5.14)

6.7.1 Activity 1.2.1.1 - Calculation of Doses Through the Ground-Water Pathway

No progress during the reporting period; this was an unfunded activity. However, individual postclosure doses were presented in the Total System Performance Assessment - 1993 documents prepared by the M&O and SNL.

Forecast: No activity is planned for FY 1995.

6.7.2 Activity 1.2.2.1 - Calculation of Transport of Gaseous Carbon-14 Dioxide Through the Overburden

No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.7.3 Activity 1.2.2.2 - Calculation of Land-Surface Dose and Dose to the Public in the Accessible Environment Through the Gaseous Pathway of Carbon-14

No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.8 GROUND-WATER PROTECTION (SCP SECTION 8.3.5.15)

6.8.1 Analysis 1.3.1.1 - Determine Whether Any Aquifers Near the Site Meet the Class I or Special Source Criteria

No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.8.2 Analysis 1.3.2.1 - Determine the Concentrations of Waste Products in any Special Source of Ground Water During the First 1,000 Years After Disposal

No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.9 PERFORMANCE CONFIRMATION (SCP SECTION 8.3.5.16)

No progress during the reporting period; this was an unfunded activity.

Forecast: No activity is planned for FY 1995.

6.10 U.S. NUCLEAR REGULATORY COMMISSION SITING CRITERIA (SCP SECTION 8.3.5.17)

No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.11 HIGHER-LEVEL FINDINGS–POSTCLOSURE SYSTEM AND TECHNICAL GUIDELINES (SCP SECTION 8.3.5.18)

6.11.1 Planning for Site Suitability Evaluation

A Federal Register notice was issued on August 4, 1994 announcing (1) the availability of Summary Reports of the May 21, 1994, stakeholder meeting held in Las Vegas, Nevada; (2) the DOE's decision to use the Siting Guidelines (10 CFR 960) as they currently exist; (3) the availability of a draft description of the process for evaluating the suitability of the Yucca Mountain site for public comment; and (4) stakeholder meetings to elicit views of the general public on the proposed process, including opportunities for external involvement. These stakeholder meetings were held August 27, 1994, in Las Vegas, Nevada, and August 30, 1994, in Washington, D.C.

The impact of the new Program Approach on the planning for site suitability evaluation is discussed in more detail in Chapter 1, Section 1.3.1 and Chapter 2, Section 2.2.1.

Forecast: Comments from the August stakeholder meetings and written comments on the draft process for evaluating site suitability will be reviewed. After the close of the public comment period, the draft process for evaluating site suitability will be revised and finalized, taking into account comments provided from the public. A Federal Register notice will be prepared and issued to provide the rationale for the DOE decision on the use of the Siting Guidelines in response to initial comments on the draft process for evaluating the suitability of the Yucca Mountain site. A second Federal Register notice will be prepared to announce the availability of the draft work scope for the peer review contract for public review in response to comments provided during the stakeholder meetings. Once the process for evaluating site suitability has been finalized, DOE will prepare an implementation plan that will implement the process for evaluating site suitability.

6.11.2 Preclosure System Technology (SCP Section 8.3.5.7)

This issue is concerned with the feasibility and availability of the technology needed to construct, operate, and close the repository.

No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

6.11.3 Preclosure Radiological Safety (Issue 4.1)

No progress during the reporting period; this was an out-year activity.

Forecast: No activity is planned for FY 1995.

CHAPTER 7 - EXPLORATORY STUDIES FACILITY DESIGN AND CONSTRUCTION

The Site Characterization Plan, Section 8.4.2, presented the rationale for planned testing and described surface testing and the underground test facility. In the Site Characterization Plan underground testing was to be conducted by means of an "Exploratory Shaft Facility." The change to a ramp and drift "Exploratory Studies Facility" means the following description of progress does not closely parallel the Site Characterization Plan structure, and as a result there are not as many references to Site Characterization Plan sections as there are elsewhere in this report.

Throughout this section reference is made to the various design packages. For the reader's ease of reference, Table 7-1 shows the package identification and description including the status at the end of the reporting period (Figure 7-1 shows locations).

7.1 EXPLORATORY STUDIES FACILITY DESIGN

Modifications, including the deletion of some elements, were made to the contents of Packages 1B, 1D, and 1E from those shown in Progress Report #10 (DOE, 1994c). Ongoing modifications in the form of Field Change Requests and Change Requests continue to be made against Design Package 1A. The design for the tunnel boring machine launch chamber in the Starter Tunnel was baselined and issued for construction early in the third quarter of FY 1994. The subsurface design drawings (tunnel boring machine Starter Tunnel) in Package 1A were converted from English to metric units to comply with "Yucca Mountain Site Characterization Project FY 1994 ESF Engineering Plan" (CRWMS M&O, 1993c). Package 1A consists of the following elements:

- North Portal pad
- Topsoil storage area
- Exploratory Studies Facility access road
- Sewage collection and treatment system
- North Portal pad water supply system (including the Booster Pump Station)
- Tunnel boring machine Starter Tunnel
- Rock storage area
- Switchgear building
- North Portal pad power distribution system (partial)

Ongoing modifications in the form of Field Change Requests and Change Requests continue to be made against Design Package 1B. The Explosive Storage Area was deleted from this package early in the fourth quarter of FY 1994 because very little drilling and blasting is being done and the bulk of the storage can be done at existing areas at the Nevada Test Site.

Table 7-1. Design Package Identification and Description

Design Package	Design Package Description	Status
4	North Portal Site Preparation and Surface Facilities	
1A	Pad, Access Road, Sewage System, Water Supply, Starter Tunnel, Switchgear Building, Power Distribution System	Issued
1B	Change House, Shop, Sewage System, Power and Water Distribution, Road Grading and Paving, Site Grounding, Surface Rail Modifications, Pad Grading and Paving Plan	Issued
1C	Compressed Air System, Stand-by Power, Site Lighting and Grounding	Issued
1D	Site Lighting and Grounding, Muck Storage, Conveyor Access Road, Fuel Storage, Equipment Foundations, Compressed Air Condensate Collection System	FY 1995
1E	Stand-by Power, Site Grounding, Electrical Distribution	FY 1995
IDCS	Integrated Data and Control System	FY 1995
2	North Ramp Excavation - Surface to Topopah Spring Level	
2A	Conveyor, Switchgear, Transformers, Power Center, Subsurface Transportation	Issued
2B	Utilities, Ventilation, Rail Haulage System, Mapping Platform, Control System, Safety Monitoring and Warning System	Issued
2C	Ground Support, Utilities, Electrical Power, Site Lighting, Site Grounding, Alcoves	FY 1995
3	South Portal Site Preparation and Surface Facilities	Out-year
4	South Ramp Excavation - Topopah Spring Level to Surface	Out-year
5	North Ramp Excavation to Calico Hills Level	Out-year
6	South Ramp Excavation to Calico Hills Level	Out-year
7	Calico Hills Level Drifting	Out-year
8	Topopah Spring Level Drifting	
8A	Ground Support, Alcoves, Utilities, Electrical System, Instrumentation System, Rail Haulage System, Conveyor, Ventilation	FY 1995
9	Topopah Spring Level - Main Test Area	Out-year
10	Optional Shaft	Out-year

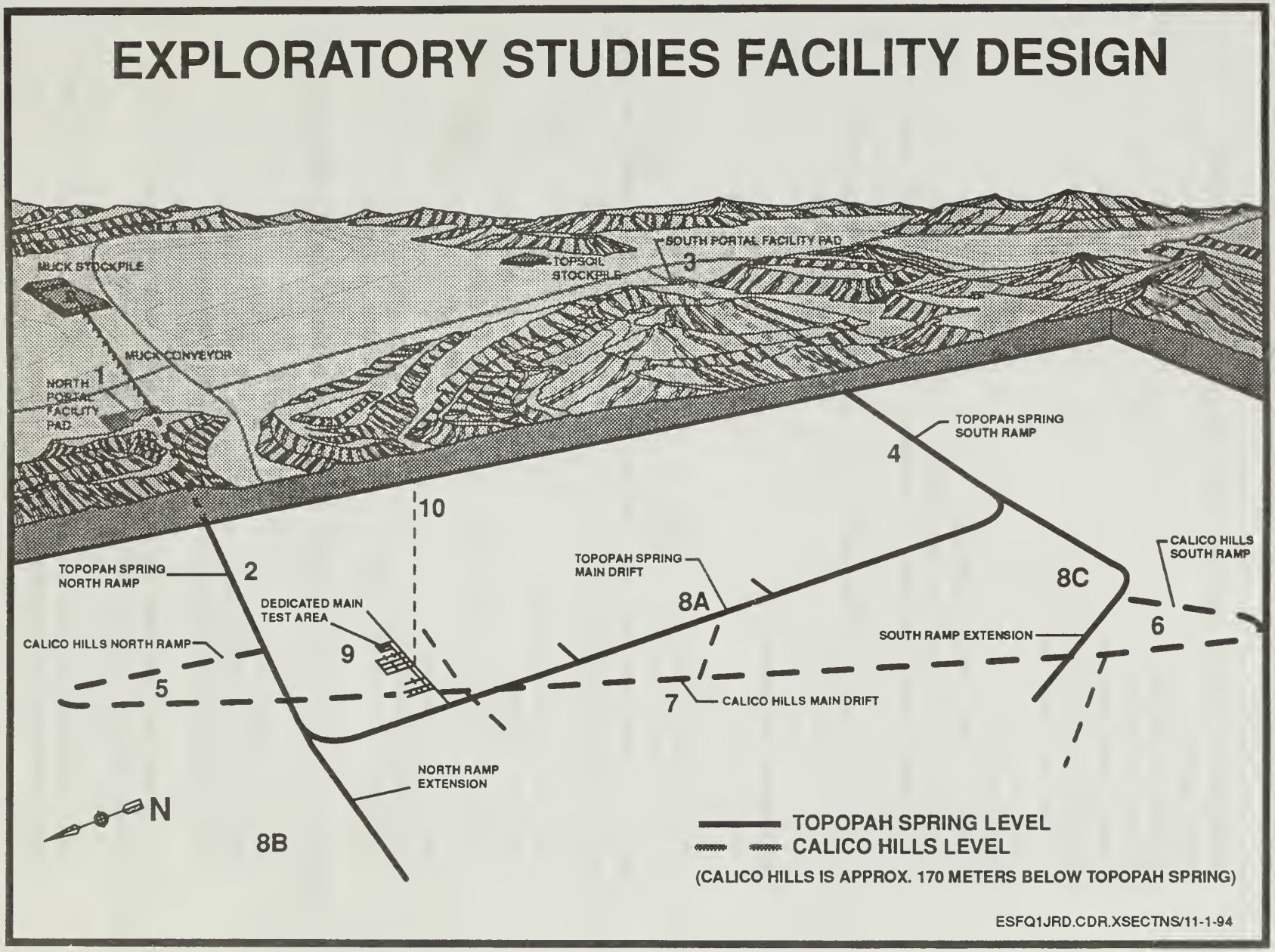


Figure 7-1. Exploratory Studies Facility Design Package Locations

Package 1B consists of the following elements:

- Change house building (contains other services to include portal control)
- Shop building
- Sanitary sewer system
- Power distribution
- Water distribution system
- Subsurface wastewater system
- H-road, site grading, and paving
- Explosive storage area (deleted)
- Site grounding
- Redesign North Portal pad drainage
- Reconfigure North Portal pad for surface rail
- Finish grading and paving plan and surface rail (added by Change Request)

Package 1C, which was baselined and issued for construction during this period, consists of the following elements:

- Compressed air system
- Stand-by power
- Site lighting (partial)
- Site grounding (partial)

Package 1D, which completed design and underwent a 90% Design Review during this period, consists of the following elements:

- Site grounding continuation
- Muck storage area
- Conveyor maintenance access road
- Fuel storage system
- Site lighting (partial)
- Equipment foundations
- Compressed air system condensate collection system

Package 1E, which will initiate design in FY 1995, consists of the following elements:

- Standby/auxiliary power
- Site grounding (continuation)
- Exploratory Studies Facility electrical distribution (continuation)

The Integrated Data and Control System Design Package, which completed a 50% Design Review during this period, consists of the following elements:

- Procurement specification for the complete Integrated Data and Control System
- Fiber Distributed Data Interface for the first phase

The Integrated Data and Control System is a control, monitoring, and data collection system to record and archive construction control and monitoring, and site characterization data for the principal investigators as well as data required by DOE Order 6430.1A (DOE, 1989). To reduce cost and optimize the system utilization, the current system combines the functions of the Integrated Data System and the Facilities Monitoring and Control System into a single system. The systems will share a data highway for communications and a single surface computer for data management and archiving. The equipment control stations and the Data Acquisition Station will remain separate and independent.

The current plan is to develop the system in phases until it becomes the completed Integrated Data and Control System. The first phase is a surface work station and data highway for connection to the initial Data Acquisition Station and the other control equipment. As the tunneling continues and more site characterization testing is initiated requiring additional Data Acquisition Stations, the data highway (Fiber Distributed Data Interface) will be expanded to its full design capability, and the surface work station will be replaced by a minicomputer capable of handling all of the data retrieval envisioned for the Exploratory Studies Facility. When the full system is in operation, approximately 150 Data Acquisition Stations will be connected through the Fiber Distributed Data Interface to the surface minicomputer.

Subsurface Design Package 2 for the North Ramp, consisting of Design Packages 2A, 2B, and 2C, was continued and is nearing completion. Minor modifications were made to the contents of Packages 2B and 2C from those shown in Progress Report #10 (DOE, 1994c). Ongoing modifications in the form of Field Change Requests and Change Requests continue to be made against Design Package 2A. Package 2A consists of the following elements:

- Surface and subsurface conveyor
- Electrical switchgear, transformers, and power center
- Subsurface transportation alternatives

Package 2B, which was baselined and issued for procurement during this period, consists of the following elements:

- Utility systems
- Tunnel ventilation specification and drawings
- Rail haulage system
- Mapping platform procurement specification
- Excavation, ventilation and muck storage trade studies
- Control system specification and drawings
- Life safety monitoring and warning system specifications

This package contains appropriate procurement information for these elements.

Package 2C, which underwent a 90% Design Review during this period, was broken into segments for issuance to support the procurement and construction schedule for the initial

phase of tunnel boring machine operations. The first segment, which supported the initial tunnel boring machine startup and test excavation, was baselined and issued during this period. Package 2C consists of the following elements:

- North Ramp to Topopah Spring Level excavation ground support
- Remaining utility systems for North Ramp
- Electrical power, lighting, and grounding
- Associated test and operational support alcoves

This package primarily contains construction and installation information for these elements as well as the elements in Packages 2A and 2B.

Package 8A design, Topopah Spring Level main drift, was initiated late in the last quarter of FY 1994. Package 8A consists of the following elements:

- Topopah Spring Level main drift excavation ground support
- Associated operational support alcoves
- Utility systems
- Electrical system
- Instrumentation system
- Rail haulage system
- Conveyor system
- Ventilation system

The original location of the septic tank and leach field, east of the North Portal Access Road, was established after considering many factors including proximity to the North Portal pad, economy, accessibility for maintenance, and good percolation for leach field effluent. Concerns had been expressed by NRC (Site Characterization Analysis Question 55) about water from surface water handling facilities percolating into the underground and affecting site characterization studies. A subsequently-issued Waste Isolation Evaluation report (CRWMS M&O, 1993d) was issued indicating that the location of the leach field could affect the ability of the conceptual repository and the potential repository expansion areas to isolate waste.

During this reporting period, the Exploratory Studies Facility Title II Design team in conjunction with personnel from Scientific Programs and Performance Assessment initiated an evaluation for a suitable location of the leach field. Based on this evaluation, it was decided that a location further southeast of the North Portal pad near the current muck storage area would be acceptable because there were no identified test interference or waste isolation impacts. This location will be implemented as part of Design Package 1E for the Exploratory Studies Facility.

Forecast: Package 1D, which underwent a 90% Design Review during this reporting period, will be baselined and issued for construction in the first quarter of FY 1995. Package 1E design will be initiated in the first quarter of FY 1995. The Integrated Data and Control System Package will undergo a 90% Design Review early in the first quarter of

FY 1995 and will be baselined and issued for construction early in the second quarter of FY 1995. Additional Integrated Data and Control System design will be performed to support expansion of the system in FY 1996. Design of the following additional Package 1 items will be completed, baselined, and issued for construction by Change Request:

- Booster pump power
- Local controls for water, Compressed Air System, and generators
- Fencing
- Lightning protection
- Modifications to Switchgear Building for Integrated Data and Control System
- Sanitary sewage treatment

The remaining segments of Package 2C will be baselined and issued for construction in the first half of FY 1995. Packages 2A and 2B, which were initially issued for procurement only, will be reissued for construction with the remaining segments of Package 2C. Based on the current budget and schedule, Package 8A will conduct a 50% Design Review in mid FY 1995, and design will be initiated on the Ghost Dance Alcoves in the third quarter of FY 1995.

7.2 TECHNICAL ASSESSMENT OF THE EXPLORATORY STUDIES FACILITY SEISMIC DESIGN

As described in Progress Report #10, the technical assessment of the Exploratory Studies Facility seismic design inputs continued during the reporting period. Twenty-four fault-specific sources and one areal source were identified in the analysis on the basis of available data. A recurrence relation and maximum magnitude were evaluated for each source and uncertainties in the inputs were assessed. Four ground motion attenuation relations were incorporated into the analysis to represent uncertainty in that parameter. The resultant values of mean peak horizontal acceleration and velocity with various annual probabilities of being exceeded are summarized below:

Table 7-2. Resultant Values of Mean Peak Horizontal Acceleration and Velocity with Various Annual Probabilities of Being Exceeded

Annual Probability of Being Exceeded	Mean Peak Horizontal Acceleration (g)	Mean Peak Horizontal Velocity (cm/sec)	Average Return Period (yrs)
2×10^{-3}	0.19	11	500
1×10^{-3}	0.27	16	1,000
5×10^{-4}	0.37	23	2,000
1×10^{-4}	0.66	45	10,000

Given the purpose of the Exploratory Studies Facility to facilitate underground exploration and testing in support of a site suitability evaluation for Yucca Mountain, the technical assessment team recommended that seismic design loading for the facility should be based on a hazard with a 90% probability of not being exceeded in 50 years (or a return period of roughly 500 years). Seismic design inputs, therefore, were developed for the hazard with an annual probability of being exceeded of 2×10^{-3}.

Disaggregation of the probabilistic seismic hazard assessment indicates that for annual exceedance probabilities greater than about 10^{-4} (return periods of less than 10,000 years), the primary source of ground motion hazard at the site is a background earthquake. At an exceedance level of 2×10^{-3}, the mean magnitude and distance of contributing earthquakes is M 5.7 at a source-to-site distance of 9 km. Response spectra were developed for such an earthquake using three approaches: (1) probabilistic equal-hazard, (2) empirical deterministic, and (3) stochastic deterministic. The recommended design response spectrum envelops the three approaches.

Peak velocity for design was determined using the band-limited white noise approach and random vibration theory. The velocity was derived to be consistent with the recommended design spectrum. For the 2×10^{-3} exceedance probability level, the design peak velocity is 12 cm/second.

The technical assessment team also evaluated the effect on ground motion caused by depth of burial below the surface. Both stochastic and empirical approaches were employed. For design, a step-function that envelops the results of the two approaches was recommended.

To evaluate the need for seismic design inputs for surface fault displacement, a simpler analysis was carried out. The recurrence intervals for surface displacement on faults within and near the site were compared with the approximately 50- to 100-year expected life of the Exploratory Studies Facility. Because the recurrence intervals for surface fault displacement are large, the technical assessment team concluded that design did not need to accommodate fault displacement.

Forecast: During the first quarter of FY 1995, the assessment of Subramanian et al. (1990) and the CRWMS M&O report on seismic design inputs for the Exploratory Studies Facility will be combined to form the review record of the technical assessment. The completed review record will be delivered to DOE.

7.3 EXPLORATORY STUDIES FACILITY CONSTRUCTION

The most notable activity during this period was the startup of the tunnel boring machine and commencement of the first phase of its checkout. Assembly of the tunnel boring machine was completed and it was moved to the rock face at the end of the Starter Tunnel. During the last part of September the tunnel boring machine was operated enough to smooth the surface and bring the tunnel boring machine head in full contact with the back wall of the tunnel and to allow checkout of various operating systems.

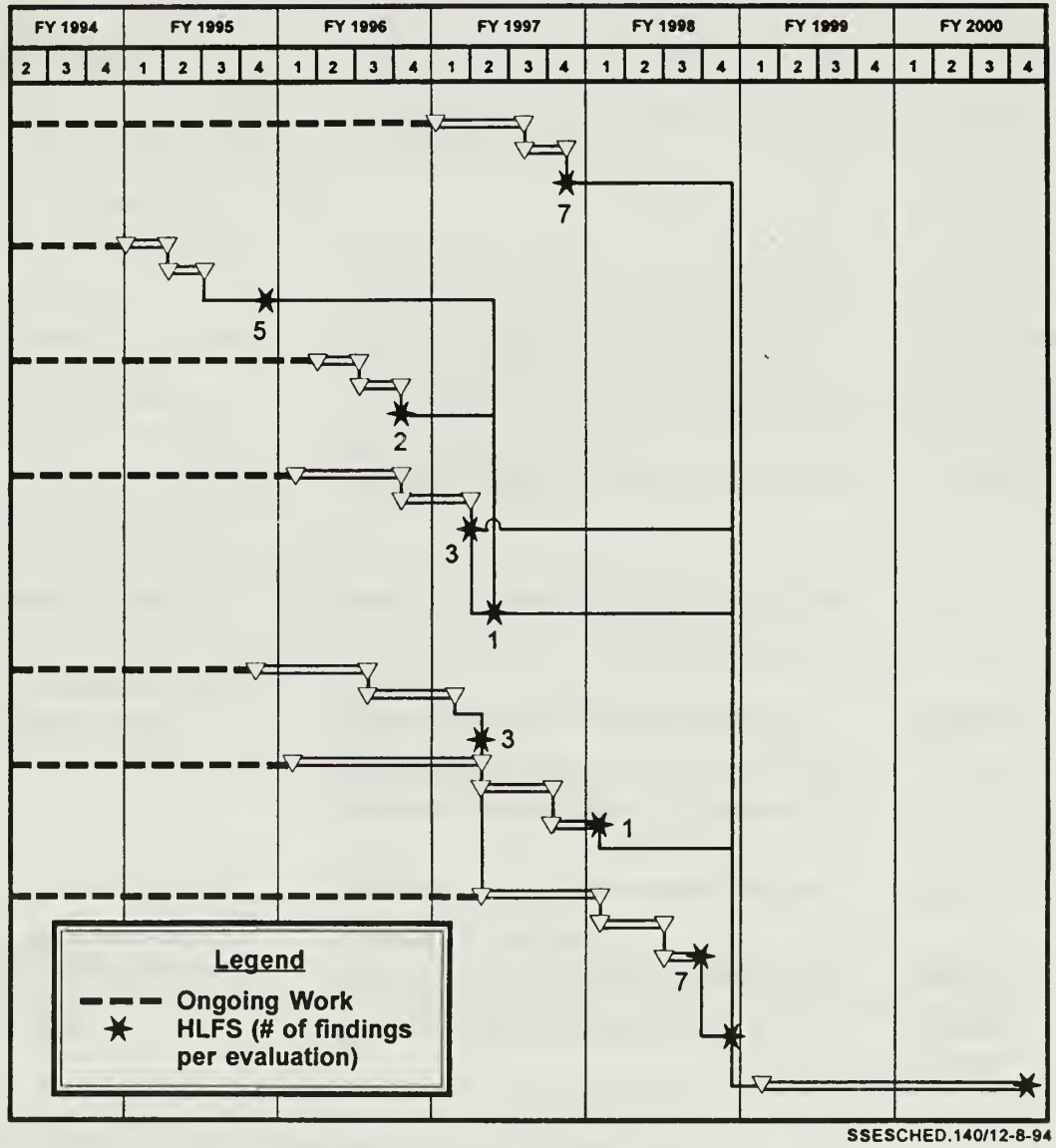
Other construction activities occurring during the period included: excavation of the water line trench from the booster pump station to the water storage tanks, construction of the water storage tank pad, completion of the electrical duct banks outside the portal and around the switchgear building and substation, start of the switchgear building foundations, installation of most of the water and sewer systems on the North Portal pad, construction of the muck car dumping facility, installation of rail from the Starter Tunnel to the shop and storage yard areas, setup of construction shops, crew shelters and storage facilities, and setup of temporary office complexes on the pad. The batch plant setup was completed as well as the adjacent precast yard for producing the concrete tunnel invert sections. First test inverts were cast late in the period.

Forecast: Activities for next period include beginning the second phase of tunnel boring machine excavation operations which will continue until the mapping gantry and decks are installed early in 1995. The switchgear building will near completion in the next period, and initial work on the change house will be well under way. The conveyor system is expected on site late in the period. Construction of the water storage tanks is planned to begin in December 1994.

APPENDIX A

Interim Evaluations in the Site Suitability Evaluation Process

Proposed Site Suitability Evaluation Schedule



PRECLOSURE RADIOLOGICAL SAFETY
- Report
- Peer Review

HLF Reg. Assessment

SURFACE PROCESSES
- Report
- Peer Review

HLF Reg. Assessment

PRECLOSURE ROCK CHARACTERISTICS
- Report
- Peer Review

HLF Reg. Assessment

TECTONICS
- Report
- Peer Review

HLF Reg. Assessment:
Postclosure Tect DSQ & Precl Tect QC and DSQ

REASONABLY AVAILABLE TECHNOLOGY:
HLF Reg. Assessment

GEOCHEM/POSTCLOSURE ROCK CHARACTERISTICS
- Report
- Peer Review

HLF Reg. Assessment: DSQS Human Intrusion/Nat. Resources

GEOHYDROLOGY/TRANSPORT
- Report
- Peer Review

HLF Reg. Assessment: Ground Water Travel Time DSQ

TOTAL SYSTEM PERFORMANCE ASSESSMENT
- Report
- Peer Review

HLF Reg Assmnt on Postclosure
Syst. & all remaining Postclosure QCs
(Geohyd, Geochm, Rock Char, Climate, Tect)

TECH. SITE SUITABILITY EVALUATION

PREPARE SITE RECOMMENDATION REPORT
& AFFIRM PREVIOUS FINDINGS

SSESCHED.140/12-8-94

Interim Evaluations in the Site Suitability Evaluation Process (Page 1 of 4)

Interim Evaluation Completion Date	Technical Basis Report	Higher-Level Finding Regulatory Assessment	Guideline Reference
Surface Processes (FY 1995)	Available information on erosion, surface characteristics, and hydrology	Postclosure Erosion Qualifying Condition and Disqualifying Condition	§960.4-2-5
		Preclosure Surface Characteristics Qualifying Condition	§960.5-2-8
		Preclosure Hydrology Qualifying Condition and Disqualifying Conditions	§960.5-2-10
Preclosure Rock Characteristics (FY 1996)	Existing information on rock characteristics and repository design concepts	Preclosure Rock Characteristics Qualifying Condition	§960.5-2-9
Tectonics (FY 1997)	Existing information on faulting, seismicity and volcanology; seismic design bases	Preclosure Tectonics Qualifying Condition and Disqualifying Condition	§960.5-2-11
		Postclosure Tectonics Disqualifying Condition and Disqualifying Condition	§960.4-2-7
Reasonably Available Technology (FY 1997)	Preceding technical basis reports for surface characteristics, rock characteristics, hydrology, and tectonics; repository design concepts	Preclosure Systems guideline for ease and cost of siting, construction, operations, and closure Qualifying Condition	§960.5-2-8, 5-2-9, 5-2-10, and 5-2-11

Interim Evaluations in the Site Suitability Evaluation Process (Page 2 of 4)

Interim Evaluation Completion Date	Technical Basis Report	Higher-Level Finding Regulatory Assessment	Guideline Reference
Geochemistry and Postclosure Rock Characteristics (FY 1997)	Available information on rock and mineral distribution, mineral alteration history, ground-water chemistry, sorption characteristics, rock mechanical properties, and natural resources	Postclosure Human Interference Disqualifying conditions	§960.4-2-2 §960.4-2-3 §960.4-2-8
		The postclosure qualifying conditions for geochemistry, rock characteristics, and human interference will be considered under the regulatory assessment for Total System Performance Assessment	
Preclosure Radiological Safety (FY 1997)	Available information on population density and distribution, site ownership and control, meteorology, offsite installations and operations; repository design concepts; dose assessment calculations	Preclosure radiologic safety system guideline Qualifying Condition	§960.5-1(a)
		Population Density and Distribution Qualifying Condition and Disqualifying Condition	§960.5-2-1
		Site Ownership and Control Qualifying Condition	§960.5-2-2
		Meteorology Qualifying Condition	§960.5-2-3
		Offsite Installations and Operations Qualifying Condition and Disqualifying Condition	§960.5-2-4

Interim Evaluations in the Site Suitability Evaluation Process (Page 3 of 4)

Interim Evaluation Completion Date	Technical Basis Report	Higher-Level Finding Regulatory Assessment	Guideline Reference
Geohydrology and Transport (FY 1998)	Potential climate change impacts on radionuclide transport, geochemistry impacts on radionuclide transport, ground-water travel time along radionuclide transport pathways	Postclosure Geohydrology Disqualifying Condition	§960.4-2-4 §960.4-2-3 §960.4-2-1
Total System Performance Assessment (FY 1998)	Total System Performance Assessment - 1997 and the preceding technical basis documents for geohydrology, geochemistry, rock characteristics, climate, and tectonics; waste package and repository design concepts	Postclosure System Guideline Qualifying Condition: System and Subsystem Requirements of 10 CFR Part 60 and 40 CFR Part 191 Postclosure Qualifying Conditions for Geohydrology, Geochemistry, Rock Characteristics, Climate, Human Interference, and Tectonics	§960.4-1 §960.4-2-1 §960.4-2-2 §960.4-2-3 §960.4-2-4 §960.4-2-7
Technical Site Suitability Evaluation (FY 1998)	Collation of preceding technical basis documents	Technical Site Suitability Determination; collation of preceding regulatory assessments	Not a 10 CFR Part 960 Requirement

Interim Evaluations in the Site Suitability Evaluation Process (Page 4 of 4)

Interim Evaluation Completion Date	Technical Basis Report	Higher-Level Finding Regulatory Assessment	Guideline Reference
Prepare Site Recommendation Report and Affirm Previous Findings (FY 2000)	Environmental, socioeconomic and transportation technical basis from Final Environmental Impact Statement: All preceding technical basis documents and current data and analyses	Preclosure Environmental Quality Systems Guideline Qualifying Condition	§960.5-1-2
		Environmental Quality Qualifying and Disqualifying Condition	§960.5-2-5
		Socioeconomic Qualifying and Disqualifying Conditions	§960.5-2-6
		Transportation Qualifying Condition	§960.5-2-7
		Site Recommendation Report	§960.3-2-4

APPENDIX B

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations (Page 1 of 5)

Organization	Date	Type	Location	Subject/Purpose
NRC	4/19/94	Technical Meeting	Bethesda, MD	Status of the Exploratory Studies Facility design and construction activities; selected design issues.
NRC	4/19-20/94	Site Visit	Yucca Mountain, NV	To provide an opportunity for NRC staff involved in research to become familiar with ongoing site characterization activities.
NRC	4/30/94	Quality Assurance Meeting	Washington, D.C.	Status of implementation of the new Quality Assurance Requirements and Description document, NRC observation of recent DOE audits, surveillance schedules, and Quality Assurance overview of site characterization field activities.
NRC	5/2-5/94	Site Visit	Yucca Mountain, NV	To provide NRC staff an opportunity to discuss characterization of faults and fractures near Yucca Mountain, and stratigraphy, structure, and rock properties along the Exploratory Studies Facility North Ramp.
NRC	5/17/94	Management Meeting	Rockville, MD	Interactions to be held between DOE and NRC during the period June through December 1994.
NRC	5/19/94	Management Meeting	Rockville, MD	To discuss DOE Program Approach and Issue Resolution topics.

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations (Page 2 of 5)

Organization	Date	Type	Location	Subject/Purpose
NRC	6/28/94	Technical Exchange	Bethesda, MD	To discuss a topical report concerning the use of burnup credit in the criticality analyses for pressurized-water reactor fuel assemblies in storage and transportation containers.
NRC	7/26/94	Management Meeting	Rockville, MD	To discuss the DOE Program Approach and Issue Resolution topics.
NRC	7/27/94	Technical Meeting	Rockville, MD	To discuss status of the Exploratory Studies Facility design and construction activities and selected design issues.
NRC	8/31/94	QA Meeting	Las Vegas, NV	To discuss the M&O Design Quality/ Quality Assurance Program.
NRC	9/21/94	Management Meeting	Rockville, MD	To discuss the site suitability evaluation process, the DOE Five-Year Plan, site characterization plan/study plan work scope consolidation, multi-purpose canister and burnup credit, and Issue Resolution.
NRC	9/27-28/94	Technical Meeting	Rockville, MD	An update on progress achieved by NRC and DOE in the area of Total System Performance Assessment.

Organization	Date	Type	Location	Subject/Purpose
ACNW	4/20-21/94	63rd Meeting	Bethesda, MD	Status of the NRC volcanology research program; current issues related to the multi-purpose canister concept; report on NWTRB saturated zone hydrology meeting; and status report on resolving the Important To Safety issue.
ACNW	5/16/94	Working Group Meeting	Bethesda, MD	To review capabilities in computer modeling and performance assessment.
ACNW	5/17-18/94	64th Meeting	Bethesda, MD	Timeliness and efficiency of work being done by the Center for Nuclear Waste Regulatory Analysis.
ACNW	6/9/94	Continuation of 64th Meeting	Bethesda, MD	To conclude unfinished agenda items from the May 17-18, 1994, meeting.
ACNW	6/29-30/94	65th Meeting	Bethesda, MD	State of Nevada comments on tectonics; NRC's Systematic Analysis regulatory process; proposed rule related to design events; and the definition of Important To Safety.
ACNW	8/16-17/94	66th Meeting	Rockville, MD	NRC's waste confidence decision; review of the DOE Program Approach; discussion of the role of the ACNW and suggested items for ACNW research; and Extreme Erosion Topical Report.

Organization	Date	Type	Location	Subject/Purpose
ACNW	9/21-22/94	67th Meeting	Rockville, MD	Presentation on the DOE Program Approach; NRC staff discussions on substantially complete containment; and proposed rulemaking for land ownership of low-level radioactive waste facilities.
NWTRB	4/11-12/94	Spring Full Board Meeting	Reno, NV	Two major topics were lessons learned from site assessment for critical facilities and a review of saturated zone hydrology at Yucca Mountain. Also, Program Approach; status of the Exploratory Studies Facility; and Advanced Conceptual Design. State of Nevada presented concerns with DOE compliance with the National Environmental Policy Act.
NWTRB	6/13-14/94	Structural Geology and Geoengineering Panel	Las Vegas, NV	Current Exploratory Studies Facility design; efforts to simplify the current design; ways to reduce the excavation schedule and costs; DOE Program Approach; and key assumptions used for the repository Advanced Conceptual Design.
NWTRB	6/15/94	Engineered Barrier System Panel	Richland, WA	Focus was in three areas: plans for processing and packaging high-level tank waste; the quantities and characteristics of irradiated materials at Hanford; and plans for the ultimate disposal of surplus weapons plutonium.

Interactions with the U.S. Nuclear Regulatory Commission and Other Organizations (Page 5 of 5)

Organization	Date	Type	Location	Subject/Purpose
NWTRB	7/12-13/94	Summer Full Board Meeting	Denver, CO	Main topics: radionuclide migration and spent fuel transportation; discussion of the DOE Program Approach; and update from the Office of the Nuclear Waste Negotiator.
NWTRB	9/12-13/94	Hydrology and Geochemistry Panel Meeting	Las Vegas, NV	Calculation of round-water travel time and importance to long-term repository performance; original intent of 10 CFR Parts 60 and 960; technical basis for the 1000-year containment criterion; and the DOE general approach to satisfying ground-water travel time requirements.
NAS	4/28/94	Committee on Technical Bases Public Meeting	Las Vegas, NV	Discussed recommendations on a standard from various interested organizations and individuals including DOE, EPA, and NRC.

APPENDIX C

Status of NRC Site Characterization Analysis Open Items

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Objection 1	Adequacy of Title I design control process.	11/2/92	NRC letter lifting Objection 1. NRC considers this objection closed.
Objection 2	Acceptability of DOE Quality Assurance Program	3/2/92	NRC letter lifting Objection 2. NRC considers this objection closed.
Comment 1	A systematic, iterative approach to identify and collect data during site characterization to support a license application not demonstrated to be in place.		Submit a supplemental response to the NRC. This response will be used to close Comments 10, 18, 49, and 60.
Comment 2	Performance Assessment: Confidence in performance.		Submit a supplemental response to the NRC.
Comment 3	Reliance on expert judgment to supply licensing information.		Supplemental response submitted to the NRC. Awaiting NRC concurrence.
Comment 4	Rationale for the testing needs; integration of testing with design and performance assessment needs.		Supply NRC with the information in semiannual progress reports. Submit a supplemental response to the NRC.
Comment 5	Waste Package: Interpretation of substantially complete containment.	7/11/94	NRC Evaluation of DOE response. NRC considers this comment closed.
Comment 6	Performance Assessment: Hypothesis Testing Table and alternative conceptual models.		Submit a supplemental response to the NRC.
Comment 7	Use of expert judgment versus peer review.		Supplemental response submitted to the NRC. Awaiting NRC concurrence.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 8	Alternative Tectonic Models		Study Plan 8.3.1.17.4.12 "Tectonic Models and Synthesis" needs to be completed and approved. Submit a supplemental response to the NRC.
Comment 9	Use of expert judgment during the development of Hypothesis Testing Table.		Submit a supplemental response to the NRC.
Comment 10	Assessment of significance of site hydrologic characteristics		Resolve concerns in Comment 1. Resolution of Comment 1 will address the cross-issues for this comment.
Comment 11	No hypothesis on the thermal effects of waste emplacement in the hydrologic environments presented.		Submit a supplemental response to the NRC.
Comment 12	Porous flow in the Calico Hills unit.	11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 13	Surface Hydrology: Surface water gaging station locations and the natural infiltration measurements.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 14	Hydrologic properties of the tuffaceous beds of the Calico Hills nonwelded unit.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 15	Solitario Canyon horizontal borehole activity is inadequate to discriminate between the hypotheses that faults are barriers to fluid flow in non-welded tuff units or faults are conduits for liquid-water flow.	9/15/94	NRC evaluation of SP 8.3.1.2.2.4. NRC considers this comment closed.

Item ID	Item Description	Closed	Action Description
Comment 16	Characterization of the hydrologic properties of the Calico Hills unit.	11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 17	Multi-purpose borehole testing near the shafts.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 18	Initial hydrologic modeling studies are not supported by planned studies.		Resolve concerns in Comment 1. Resolution of Comment 1 will address cross-issues for this comment.
Comment 19	Saturated Zone: Work is not adequate for saturated zone characterization		Submit a supplemental response to the NRC.
Comment 20	Saturated Zone: Potentiometric surface will not adequately be defined.		Submit a supplemental response to the NRC.
Comment 21	Saturated Zone: Tc-199 and I-129 are not included to be characterized in the ground water flow and radionuclide analysis background concentrations.		DOE letter to NRC closing Comment 21 and 22. Awaiting NRC concurrence.
Comment 22	Saturated Zone: Hydrochemical samples.		DOE letter to NRC closing Comments 21 and 22. Awaiting NRC concurrence.
Comment 23	Unsaturated Zone: Evaluation of radionuclide concentrations on fracture surfaces.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 24	Approaches are not sufficient for determining reliable thermodynamic properties.		Receive Study Plan from Los Alamos National Laboratory. Original Administrative Procedure had to be rewritten and resubmitted because of length of time. Los Alamos National Laboratory budgeted for work in 1994.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 25	Waste Package: Rationale on additional testing on waste and interactions between and among radionuclides on sorption.		Submit a supplemental response to the NRC.
Comment 26	Sorption Batch Studies	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 27	Batch Sorption Measurements	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 28	Sorption on Particulates and Colloids.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 29	Biological Sorption and Transport.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 30	Solubility Modeling.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 31	Some parameters and conditions under fracture flow are not planned and need to be determined.		Submit a supplemental response to the NRC.
Comment 32	Rock characteristics program: Geophysical integration is insufficient.		Geophysical Integration Group needs to develop a plan to implement integration. Submit a supplemental response to the NRC.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 33	Engineering rock parameters are not adequately integrated to develop 3-D rock characteristics models		Prepare Study Plan 8.3.1.4.2.3 "Three-Dimensional Geologic Modeling" and submit to the NRC. Complete Study Plan 8.3.1.4.3.1 "Systematic Acquisition of Site Specific Data" and submit to the NRC. Submit a supplemental response to the NRC.
Comment 34	Drilling Program: It is unclear how data from various drill holes will be used in support of various studies, how uncertainties in core retrieval and data analyses will be handled, and how the large volume of existing information will be used to plan the drilling program.		Submit a supplemental response to the NRC.
Comment 35	Adequacy of lithological, structural, and drifting activities to characterize the site.	11/2/92	NRC considers this comment closed. NRC letter lifting Objection 1.
Comment 36	Rationale for investigation 8.3.1.4.2 may not be accurate for the perimeter drift defining lower concentrations of faults.		Supplemental response submitted to NRC . Awaiting NRC concurrence
Comment 37	Identification of blast fractures.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 38	Characterization of faults in the subsurface.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 39	Systematic Drilling Program: No assessment is provided to support the estimated maximum range of statistical correlation for porosity and air permeability.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 40	Systematic Drilling Program: Spacing of the 30 sample borehole pairs in a range of up to 10,000 feet may represent a lower bound for geostatistical analysis.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 41	Systematic Drilling Program: Tight clustering of sample locations SD-8 and SD-12 has not been justified	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 42	Adequacy of evaluation of escarpment retreat.		DOE letter on comments 42 & 43. Awaiting NRC concurrence.
Comment 43	Adequacy of numerical goals in erosion, post-closure tectonics, and pre-closure tectonics performance assessment tables.		DOE letter on comments 42 & 43. Awaiting NRC concurrence.
Comment 44	Waste Package: Overall goal is not consistent with substantially complete containment	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 45	Volcanic rate calculations independent of underlying volcanic-tectonic processes.		Supplemental response submitted to NRC. Awaiting NRC concurrence.
Comment 46	Postclosure Tectonics.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Item ID	Item Description	Closed	Action Description
Comment 47	Waste Package: Relationship of postclosure tectonics to the waste package and the EBS requirements.		Supplemental response submitted to the NRC. Awaiting NRC concurrence.
Comment 48	Use of fault slip rates on the repository facilities are not conservative.		Submit a supplemental response to the NRC.
Comment 49	Volcanism: Results from investigations on basaltic volcanism may fail to meet overall system performance.	9/14/94	NRC evaluation of SP 8.3.1.8.1.2. NRC considers this comment closed.
Comment 50	Effects of faulting may be underestimated.	7/31/91	NRC evaluation of DOE responses. NRC considers the comment closed.
Comment 51	Adequacy of Geophysics program to determine deep and shallow crustal features.	11/8/94	Ltr. Shelor to Holonich, dtd. 11/8/94; Staff Evaluation of Open Item Responses on Waste Package Design and Waste Package Failure Modes, The NRC Staff considers Item 51 Closed
Comment 52	Use of Geophysics to identify volcanic/igneous features.		Complete assessment by independent consultant of planned and potential geophysical studies that could be contributed to resolution of volcanism issue. Supply consultant's preliminary findings to the NRC for use during the technical exchange. Submit a supplemental response to the NRC.
Comment 53	Adequacy of natural resource assessment; consideration of ore deposition models.		NRC Ltr. 2/18/94 Holonich to Shelor partially closing SCA Comment 53.
Comment 54	Inconsistencies in Site Characterization Plan Chapter 8.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 55	Adequacy of geostatistical approach to geomechanical and thermal properties.		The review of Performance Allocations for Activity 8.3.1.15 "Rock Characteristics Program" needs to be completed. Submit a supplemental response to the NRC.
Comment 56	Validation of models for mechanical and thermal properties.		Complete and supply NRC with study plans relating to in situ tests. 8.3.1.15.1.5, rev.1 "Excavation Investigations," 8.3.1.15.1.6 "In Situ Thermomechanical Properties," and 8.3.1.15.1.7 "In Situ Mechanical Properties" The Review of Performance Allocations for Activity 8.3.1.15 "Rock Characteristics Program" needs to be completed. Submit a supplemental response to the NRC.
Comment 57	Design verification does not consider alternative methods of excavation.	11/2/92	NRC letter lifting Objection 1. NRC considers comment closed.
Comment 58	Descriptions in the in situ design verification section do not include tests to verify design reports.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 59	Description of tectonic and igneous events do not allow for determination of actual investigations to be conducted, and sequencing of activities.		Submit a supplemental response to the NRC.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 60	Performance Assessment: Adequacy of preclosure design and performance goals and characterization parameters.		Resolve concerns in Comment 1. Resolution of Comment 1 will address cross-issues of this comment.
Comment 61	Assumption that future faulting will follow previous faulting.		Submit a supplemental response to the NRC.
Comment 62	The studies of faulting at the surface facilities do not indicate how DOE is proposing to use standoff distances.		Submit a supplemental response to the NRC.
Comment 63	Use of pre-existing and unavailable information for the preclosure tectonics program and the surface facilities.		Submit a supplemental response to the NRC which will describe where in the study plan and the "Test and Evaluation Plan" the concerns of the NRC are addressed.
Comment 64	Adequacy of faults study for design and performance.		Conduct a NRC/DOE interaction to further discuss the identification and investigation of fault displacement and seismic hazards. Submit a supplemental response to the NRC.
Comment 65	Use of domains to define areas of faulting potential	7/31/91	NRC evaluation of DOE response. NRC considers this comment closed.
Comment 66	Release via a single event 10,000 year cumulative slip earthquake.		Complete detailed study to show the facility can conservatively withstand an event exceeding the design basis ground motion. Submit a supplemental response to the NRC.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 67	Data on earthquakes having a cutoff of a magnitude 5.5 may not be sufficient to support an evaluation of the effects of site geology on surface and subsurface motion.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 68	Adequacy of treatment on detachment faulting affects.		Prepare Study Plan 8.3.1.17.4.12 "Tectonic Models and Synthesis" and submit to the NRC. Submit a supplemental response to the NRC.
Comment 69	Synthesis of data on the northwest trending faulting.		Prepare Study Plan 8.3.1.17.4.12 "Tectonic Models and Synthesis" and submit to the NRC. Submit supplemental response to the NRC.
Comment 70	Blast control procedures are less important to post-closure performance not justified.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 71	Adequacy of technologies in assessing faulting for construction, operation, and closure.		Submit a supplemental response to the NRC.
Comment 72	Adequacy of the seal program.	11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 73	Performance Assessment: Adequacy of required backfill hydraulic conductivity.		Resume work on the seals program investigation. Prepare the study plan for the measurement of the hydraulic conductivity (there is no numeric designator for this SP yet). Submit a supplemental response to the NRC.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 74	Testing of Seal Components: No indication is given as to whether and when the testing to evaluate the behavior of selected sealing components under in situ test conditions will be initiated.		Prepare Study Plan 8.3.3.2.2.3 "In Situ Testing of Seal Components." Submit a supplemental response to the NRC.
Comment 75	Definition of and inconsistent use of geologic setting.	12/30/93	NRC Evaluation of DOE Responses. NRC considers this comment closed.
Comment 76	NRC reviews cannot be relied on as peer reviews.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 77	Adequacy of considerations of retrieval operations in evaluating the effects of credible accidents on radiological exposure.		Evaluate the effects of credible accidents on radiological exposures during retrieval operation of the Advanced Conceptual Design. Submit a supplemental response to the NRC.
Comment 78	10 CFR Part 20 requirements need to be considered for postclosure.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 79	Waste Package: Adequacy of waste package corrosion tests for the repository.		Complete the reviews and revisions of Study Plan 8.3.4.2.4.1 "Characterization of Chemical and Mineralogical Changes in the Post Emplacement Environment" and submit to the NRC. Supply the NRC with the Lawrence Livermore National Laboratory report, "Metal Barrier Selection and Testing," LLNL SIP CM-01. Submit a supplemental response to the NRC.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 80	Performance goals consistent with interpretation and intent of substantially complete containment.		Submitted a supplemental response to the NRC. Awaiting NRC concurrence. NRC maintained the item as open. Submit additional supplemental response to the NRC.
Comment 81	Waste Package: Adequacy of program in stress corrosion cracking behavior of waste packages.		The metals barriers scientific investigation plan to be completed. Evaluation of the extended dry concept with drift emplacement needs to be completed which may make this concern moot. The metals barrier scientific investigation must be initiated and preliminary results released. Submit a supplemental response to the NRC.
Comment 82	Waste Package: There is an inadequate discussion on how the waste package performance may be verified at the time of license application.		Prepare Study Plan 8.3.4.2.4.4 "Engineered Barrier System Field Test" and submit to the NRC. Submit a supplemental response to the NRC.
Comment 83	The term 'uniform corrosion' is misleading.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 84	Issue resolution strategy and testing package for the waste package and Engineering Barrier System do not take into account the full range of likely natural conditions that might affect performance of the barrier.		Consider the effect of unanticipated processes and events on the overall system in the ongoing issue resolution process. Submit a supplemental response to the NRC.

Item ID	Item Description	Closed	Action Description
Comment 85	Performance Assessment: Temporal changes in the state of stress due to corrosion of the container is not accounted for.		The metals barriers scientific investigation plan to be completed. Evaluation of the extended dry concept with drift emplacement needs to be completed which may make this concern moot. The metals barrier scientific investigation must be initiated and preliminary results released. Submit a supplemental response to the NRC.
Comment 86	Waste Package: Degradation modes of copper-based alloys do not appear to agree with scientific literature.		Complete the degradation modes surveys for candidate materials and test plans for promising materials. Submit a supplemental response to the NRC.
Comment 87	Waste Package: Adequacy of effects of dissimilar metal contacts causing corrosion.		Advance the waste package design which will narrow the waste package option down to three designs. Describe the use of data from galvanic testing in the waste package design plan. Submit a supplemental response to the NRC.
Comment 88	Waste Package: Assumption of reduced uncertainties because of the unsaturated zone.		Lawrence Livermore National Laboratory scientific investigation SIP-CM-01 (Rev. 1), "Metal Barrier Selection and Testing" needs to be completed and supplied to the NRC.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 89	Waste Package: Construction materials may change the local pH and affect the corrosion of the metal containers and the leach rates of radionuclides from the glass.		Prepare Study Plan 8.3.4.2.4.5 "Manmade Materials" and submit to the NRC. Submit a supplemental response to the NRC.
Comment 90	Waste Package: Consideration of varying oxygen concentrations on the corrosion of metal containers.		Provide details on how the effects of oxygen on the waste package will be considered. These details will be described in the metal barriers investigation plan. Complete evaluation of the drift emplacement alternative. This alternative would make this concern moot. Submit a supplemental response to the NRC.
Comment 91	Waste Package/Performance Assessment: Consideration of alternative canisters for C-14 releases.		Evaluate and describe performance of alternative waste package designs to be considered in Advanced Conceptual Design. Review the new Environmental Protection Agency standards when they become available. Alternative waste package scenarios need to be developed. A robust design may make this concern moot. Submit a supplemental response to the NRC.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 92	Disturbed Zone: Boundary definition does not include properties affected by heat generated by waste emplacement	7/31/91	NRC evaluation of DOE responses. NRC considers the comment closed.
Comment 93	Performance Assessment: Will the site meet the performance objective for prewaste emplacement.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 94	Performance Assessment: Assumption about features, events, processes related to the hydraulic systems in the modeling strategy.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 95	Performance Assessment: Logic used to develop and screen scenarios and its implementation appear to be deficient.		Supplemental Response submitted to the NRC. Awaiting NRC concurrence.
Comment 96	Adequacy of the use of Kd for modeling heterogeneous medium.		Complete and submit to the NRC Study Plans 8.3.1.3.4.1"Sorption Study." 8.3.1.3.4.3 "Development of Sorption Models," and 8.3.1.3.5.1 "Dissolved Species Concentration Limit." Submit a supplemental response to the NRC.
Comment 97	Adequacy of evidence to eliminate iodine as an important radionuclide.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Item ID	Item Description	Closed	Action Description
Comment 98	Performance Assessment: Appropriateness of weighting Complementary Cumulative Distribution Functions by expert judgment.		Continue the development of the alternative conceptual models. Address the Complementary Cumulative Distribution Functions through the iterative TSPA process. Prepare and provide the NRC with documentation on the TSPA and sensitivity studies (related to schedule in Comment 9). Submit a supplemental response to the NRC.
Comment 99	Performance Assessment: Quantification of all release		DOE/NRC Technical Exchange on Scenarios and Complementary Cumulative Distribution Functions. Submitted a supplemental response to the NRC. NRC maintained item as open
Comment 100	Performance Assessment: Adequacy of considerations of faulting release scenarios.	2/8/93	NRC letter closing 7 Site Characterization Analysis comments.
Comment 101	Performance Assessment: Appropriateness of equation used to estimate the partial performance for the 4th scenario class involving release along the water pathway.		NRC/DOE technical exchange on scenario development. Supplemental response submitted to the NRC. Awaiting NRC concurrence.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 102	Performance Assessment: Adequacy of Ross sequences in comparison to the hydrologic flow model.		Submitted a supplemental response to the NRC. NRC maintained the item as open.
Comment 103	Performance Assessment: Ross sequences address anticipated conditions and not scenarios.		Submitted a supplemental response to the NRC. NRC maintained the item as open.
Comment 104	Performance Assessment: Ross sequences address spent fuel but not vitrified waste form.	2/8/93	NRC letter closing 7 Site Characterization Analysis comments.
Comment 105	Performance Assessment: Rationale for elimination of scenarios.		Supplemental response submitted to the NRC. Awaiting NRC concurrence.
Comment 106	Performance Assessment: Missing coupling term for calculation of liquid phase radionuclide transport.	2/8/93	NRC letter closing 7 Site Characterization Analysis comments.
Comment 107	Performance Assessment: Awaiting time in calculation is OK but care needs to be taken in the empirical Complementary Cumulative Distribution Functions in approximating.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 108	Performance Assessment: Use of the Estimated Partial Performance Measures to screen scenarios and establish goals.	2/8/93	NRC letter closing 7 Site Characterization Analysis comments.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 109	Performance Assessment: Adequacy of treatment of coupling time between matrix and fracture flow in hypothesis testing tables.		Continue Total System Performance Analysis activity which will continue to analyze the coupling times for the transfer of radionuclides between matrix and fracture flow. Submit a supplemental response to the NRC.
Comment 110	Performance Assessment: Adequacy of dealing with human intrusion in the Complementary Cumulative Distribution Function.	2/8/93	NRC letter closing 7 Site Characterization Analysis comments.
Comment 111	Inconsistencies exist in the Site Characterization Plan on Total System Performance.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 112	Adequate discussion of state variables as constants or as random variables.	2/8/93	NRC letter closing 7 Site Characterization Analysis comments.
Comment 113	Consistency of definition of Complementary Cumulative Distribution Function and the unit step function.	2/8/93	NRC letter closing 7 Site Characterization Analysis comments.
Comment 114	The term 'independent' is used instead of 'mutually exclusive.'	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 115	Adequacy of expanding of Complementary Cumulative Distribution Function in terms of scenario classes.		Submitted a supplemental response to the NRC. Awaiting NRC concurrence.

Item ID	Item Description	Closed	Action Description
Comment 116	Individual exposures via potable water may need to be expanded.		Issuance by the Environmental Protection Agency of a new standard (40 CFR 191) for individual exposure standards per the Energy Policy Act of 1992. Revise issue resolution strategy for Site Characterization Plan Issue 1.2. Prepare additional response to NRC. Submit revised issue resolution strategy and response to NRC.
Comment 117	Individual exposure rate of C-14 may need to consider advective and diffusive flow rates.		Submit a supplemental response to the NRC.
Comment 118	The monitoring and testing activities should include long-term in situ and long-term waste package activities		Determine testing requirements after site characteristics have advanced far enough to define the performance program. Submit a supplemental response to the NRC.

Status of NRC Site Characterization Analysis Open Items

Item ID	Item Description	Closed	Action Description
Comment 119	Performance Confirmation: The information presented is insufficient to determine if the confirmation program meets the requirements of 10 CFR 60.		Conduct NRC/DOE interaction on the performance confirmation program. Prepare Study Plan 8.3.3.2.2.3 "In Situ Testing of Seal Components" and then submit to the NRC for acceptance. Prepare Study Plan 8.3.1.15.1.6 "In Situ Thermo-mechanical Properties" and submit to the NRC. Prepare Study Plan 8.3.4.2.4.4 "Engineered Barrier Field Tests" and submit to the NRC. Submit a supplemental response to the NRC.
Comment 120	Model and computer code validation studies.		Prepare and provide to the NRC the model and computer code validation strategy. Submit a supplemental response to the NRC.
Comment 121	Exploratory Shaft Facility: Adequacy of seismic design of Exploratory Shaft Facility.		Exploratory Shaft Facility Design Requirements issued.
Comment 122	Demonstration and acceptability of the dry coring method.		Submitted a supplemental response to NRC. Awaiting NRC concurrence.
Comment 123	Assessment of effects of ventilation on the Exploratory Shaft Facility.	6/21/94	Ltr. Holonich to Shelor, NRC considers this comment closed.
Comment 124	Potential causes for a reduction in the drainage capacity.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Item ID	Item Description	Closed	Action Description
Comment 125	Existing data used in the licensing process needs to be qualified.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 126	Items covered by 10 CFR Part 60 (G) are incomplete.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 127	Design Acceptability Analysis.	11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 128	Requirements applicable to the Exploratory Shaft Facility.	11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 129	Design Acceptability Analysis and the Exploratory Studies Facility Design Requirements do not consider 10 CFR 60 requirements.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 130	Only 22 of fifty-two (52) requirements applicable to the Exploratory Shaft Facility were focused on in the Title I design. The rigor and completeness of the Design Acceptability Analysis are questioned.		Prepare a supplemental response after the ESFDR document is issued. The response will identify where in the ESFDR document the 29 requirements are addressed and discuss how the 30th requirement is addressed by the SCP.
Comment 131	Design Acceptability Analysis.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.
Comment 132	Design Acceptability Analysis.	11/2/92	NRC letter lifting Objection 1. NRC considers this comment closed.
Comment 133	Design Acceptability Analysis.	7/31/91	NRC evaluation of DOE responses. NRC considers this comment closed.

Status of NRC Site Characterization Analysis Open Items

Item ID		Item Description	Closed	Action Description
Question	1	Integration of mapping efforts.	12/30/93	NRC evaluation of DOE responses. NRC considers this question closed.
Question	2	Performance Assessment: Relation between mechanical and hydraulic apertures.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	3	Repository Design: Rationale used for selecting the total repository area is not presented.		Submitted a supplemental response to the NRC. Awaiting NRC concurrence
Question	4	Adequacy of temperature logging to evaluate anomalously low heat flow.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	5	Adequacy of vertical boreholes for evaluation of faults and fractures.		Submitted a supplemental response which discusses the reconfiguration of the Exploratory Shaft Facility and its use for evaluating faults to the NRC. Awaiting NRC concurrence.
Question	6	Meaning of statement in last paragraph page 8.3.1-75.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	7	Face mapping of exploratory drifts restricted to areas of anomolous conditions.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	8	Rock Properties: Level of detail and uncertainty in 3D model.		Submit a supplemental response to the NRC.
Question	9	Systematic Drilling Program: Adequacy of sampling same sequences for rock properties.		Complete review of Study Plan 8.3.1.4.3.1 "Systematic Acquisition of Site-Specific Subsurface Information" and submit to the NRC.
				Submit a supplemental response to the NRC.

Item ID		Item Description	Closed	Action Description
Question	10	How will 3D block model account for variability in the block?	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	11	Rationale to start drilling prior to approval of study plans.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	12	Rationale for exclusion of lunar crater basaltic field as natural analog.		NRC Phase II review of Study Plan 8.3.1.8.1.1 "Probability of a Volcanic Eruption Penetrating the Repository" completed. Submitted supplemental response to the NRC. Awaiting NRC concurrence.
Question	13	Basis for statements made about the migration, structural boundaries, and stage of volcanism.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	14	Natural Resources: Adequacy of evaluation of previous mining and drilling leases.	2/18/94	NRC evaluation of DOE responses. NRC considers this question closed.
Question	15	Resource exploration and mineral resource potential.	2/18/94	NRC evaluation of DOE response. NRC considers this question closed.
Question	16	Methods for determining the impact of ground motion from underground nuclear explosions.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	17	Rock Properties: Activities to investigate effects on	4/21/93	NRC considers comment closed. (Letter- Shelor to Holonich)
Question	18	Allowable movements on joints related to rock mass strength.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.

Status of NRC Site Characterization Analysis Open Items

Item ID		Item Description	Closed	Action Description
Question	19	Side Looking Airborne Radar (SLAR).	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	20	Repository Design: Discussion of vertical or horizontal emplacement.		Prepare a supplemental response describing how the Advanced Conceptual Design will address this issue. Submitted a supplemental response to the NRC. Awaiting NRC concurrence.
Question	21	Process to assure the parameters for performance goal C2 (radiation shielding of rock) is comprehensive enough and expected values realistic.		Further develop the advanced conceptual design. Submit a supplemental response to the NRC.
Question	22	Parameters related to repository construction and operation.		Develop performance goals for the repository as part of the Advanced Conceptual Design.. Submitted a supplementsl response to the NRC. Awaiting NRC concurrence.
Question	23	Computer code verification and validation.		Submit a supplemental response to the NRC.
Question	24	Justification that the shaft liner does not provide structural support for the formation.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	25	Heterogeneous air flow characteristics for seal program.		Submitted a supplemental response to the NRC. Awaiting NRC concurrence.
Question	26	Inconsistency between tentative Design Goals and Design Performance Goals.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.

Item ID		Item Description	Closed	Action Description
Question	27	Storage capacity at base of shaft for attaining the tentative design goals.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	28	ES-1 penetration of the Calico Hills Unit: Impacts of the current sealing program and issue resolution strategy 4.4.		Prepare seal design concepts (Sandia National Laboratories). Conduct performance assessment of seal program. Submit a supplemental response to the NRC.
Question	29	Justification that references sited present results representative of conditions at Yucca Mountain.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	30	Waste Package: Water quality as related to waste package design.		Complete the activities in the metal barriers scientific investigation plan and waste form scientific investigation plan. Complete evaluation of the drift emplacement alternative needs. This alternative would make this concern moot. Submit a supplemental response to the NRC.
Question	31	Waste Package: Integrity of spent fuel cladding.		Submitted a supplemental response to the NRC. Awaiting NRC concurrence.
Question	32	Waste package: Container 'similarity' for borosilicate glass waste vs. spent fuel.		Advance the waste package design and narrow the waste package options down to three designs. Submit a supplemental response to the NRC.

Item ID	Item Description	Closed	Action Description
Question 33	Waste Package: Emplacement hole drainage concerns.		Evaluate water-vapor interface, crevice corrosion, and galvanic corrosion testing in the metal barriers scientific investigation plan during Advanced Conceptual Design. Complete evaluation of the drift emplacement alternative. This alternative would make this concern moot. Submit a supplemental response to the NRC.
Question 34	Waste Package/ Performance Assessment: Meaning of undetected defective closures.		Submit a supplemental response to the NRC.
Question 35	Waste Package: Acceptance criteria for helium leak results.		Submitted a supplemental response to NRC. Awaiting NRC concurrence.
Question 36	Waste Package: Contact of canisters with corrosive elements during shipping and handling.		Advance the waste package design and narrow options down to three designs. Submit a supplemental response which will further address the issue of eliminating corrosion elements during manufacture of the container to the NRC.
Question 37	Waste package: Basis for 10-cm of free fall for canister and contents.		Submit a supplemental response to the NRC which will show when and how during the waste package container design and testing, the drop height of the container will be addressed.
Question 38	What is the basis for the 1-mm thinning criterion for waste package scratching.		Submitted a supplemental response to the NRC. Awaiting NRC concurrence.

Status of NRC Site Characterization Analysis Open Items

Item ID		Item Description	Closed	Action Description
Question	39	Waste Package: Defining 'unusual process history' of canister.		Advance the design of the waste package. Submit a supplemental response to the NRC.
Question	40	Waste Package: Basis for factor of 2 on borehole liner in comparison to container material.		Study effects of water containing liner corrosion products on degradation of the container in accordance with the metal barriers scientific investigation plan. Submit a supplemental response to the NRC.
Question	41	Repository: Consideration of 10 CFR 60.132 (a) in resolution of Issue 2.4.		Conduct engineering studies to evaluate the waste throughput requirements. Submit a supplemental response to the NRC.
Question	42	Repository: Assumption of stability of vertical emplacement hole.		Advance the Advanced Conceptual Design. Drift emplacement may make this comment moot. Submit a supplemental response to the NRC.
Question	43	Waste Package: Anticipated operational occurrences considered part of normal conditions on the preclosure design and analysis.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.

Status of NRC Site Characterization Analysis Open Items

Item ID		Item Description	Closed	Action Description
Question	44	Waste Package/Performance Assessment: Basis for assumed numbers of breached assemblies or canisters.		Provide information on failures of waste forms in multiple locations. Prepare and provide the NRC with documentation on the Total System Performance Assessment. Advance the Advanced Conceptual Design and narrow options to two candidate designs. Submit a supplemental response to the NRC.
Question	45	Waste Package: Investigation of particulate source terms, retention factors, and plate-out of waste package during accident conditions.		Submitted a supplemental response to the NRC. Awaiting NRC concurrence.
Question	46	Waste Package: Basis for stricter containment of long half-life isotopes.	7/11/94	NRC evaluation of DOE response. NRC considers this question closed
Question	47	Waste Package: Assumption on breached waste containers.		Submitted a supplemental response to the NRC. NRC maintained item as open. Submitted an additional supplemental response to the NRC. Awaiting NRC concurrence.
Question	48	Waste Package: Selection of peer review panel on waste package.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	49	Waste Package: Effects of low temperature oxidation on containers.		Complete the metal barriers scientific investigation plan. Advance the design of the waste package to three options. Submit a supplemental response to the NRC.

Status of NRC Site Characterization Analysis Open Items

Item ID		Item Description	Closed	Action Description
Question	50	Waste Package: Assumption that stress propagation results in corrosion.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	51	Design second research criteria for accepting waste from Idaho National Engineering Laboratory and Hanford.	11/8/94	NRC evaluation of DOE response. NRC considers this question closed.
Question	52	Waste Package: Leaching properties specification will require the producer to control leaching characteristics of the glass waste.	7/31/94	NRC evaluation of DOE responses. NRC considers this question closed.
Question	53	Waste Package: Specification of cooling rate of the glass waste.		Supplemental response submitted to NRC. Awaiting NRC concurrence.
Question	54	Waste Package: Release rates of radionuclides from spent fuels.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	55	Exploratory Shaft Facility: Interference at the Exploratory Shaft Facility by waste storage tanks, septic field, and waste water lagoon.		Submit a supplemental response to the NRC
Question	56	Basis for 5 cm of fault displacement in waste package environment.		Submitted a supplemental response to the NRC. Awaiting NRC concurrence.
Question	57	Effects of drilling multipurpose boreholes.		Supplemental response submitted to the NRC. Awaiting NRC concurrence.
Question	58	Flexibility of the Exploartory Shaft Facility design to accommodate in situ testing of the waste package, if required.		Submitted a supplemental response to the NRC. Awaiting NRC concurrence.

Status of NRC Site Characterization Analysis Open Items

Item ID		Item Description	Closed	Action Description
Question	59	Basis for length of in situ thermal tests.		Prepare Study Plan 8.3.1.15.1.6 "In Situ Thermomechanical Properties" and submit to NRC. Submit a supplemental response to the NRC.
Question	60	Exploratory Shaft Facility: Timing of Exploratory Shaft Facility radial borehole test.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.
Question	61	Exploratory Shaft Facility: Accommodation of design changes during Exploratory Shaft Facility construction.	11/2/92	NRC letter lifting Objection 1. NRC considers this question closed.
Question	62	Repository: Basis for 500 feet of separation from Exploratory Shaft Facility and waste emplacement panel.		Submit a supplemental response to the NRC.
Question	63	Certifying Training Attendance Record reviewers were not principal investigators.	7/31/91	NRC evaluation of DOE responses. NRC considers this question closed.

APPENDIX D

Change Control Board Actions
April 1, 1994 - September 30, 1994

Change Control Board Actions April 1, 1994 - September 30, 1994

Surface-Based Testing Changes

Title	Change Description	Status
C-Well Discharge Pipeline	Add two drawings to technical baseline register and issue them for construction.	Closed
Boreholes UE-25 NRG #2C and #2D Program Addition	Adds geophysical logging program to original Job Package/Test Planning Package.	Closed
Borehole USW UZ-14 Program Addition	Adds geophysical logging program to original Job Package/Test Planning Package.	Closed
C-Well Complex Pump Tests Electrical Package	Adds four drawings and one specification to the Project Change Control Board Register.	Closed
Baseline the C-Well Complex Civil Design Document	Adds four drawings and one specification to the Project Change Control Board Register.	Closed
Extend Drilling of Borehole USW SD-9	Drills Borehole USW SD-9 to depth of 2175 feet.	Closed
UE-25 NRG #5 Borehole Pad and Access Road	Adds four drawings and one specification to the Project Change Control Board Register.	Closed
UE-25 NRG #4 Borehole Access Road	Adds three drawings and one specification to the Project Change Control Board Register.	Closed
Job Package 94-13, Rev. 0	Adds to Job Package 94-13, Rev. 0, to Project Change Control Board Register.	Closed

Change Control Board Actions April 1, 1994 - September 30, 1994

Requirements and Management Documents

Title	Change Description	Status
Revision to Site Characterization Program Baseline	Combines three tectonic studies; deletes evaluation of Curie Temperature Study and 10,000-year cumulative slip concept from baseline.	Closed
Exploratory Studies Facility Design Requirements Interim Change Notice 1: Remove Requirement to Sample Blasting Byproducts	Removes requirement to sample blast byproducts and 19 related TBDs.	Closed
Site Design and Test Requirements Document	Revises requirements pertaining to site characterization and design. Generates Requirements Backup Sheets with rationale for each of the requirements.	Closed
Exploratory Studies Facility Design Requirements document Interim Change Notice 2	Modifies the Exploratory Studies Facility portions pertaining to the verification of Design Package 2C. Also removes TBVs.	Closed
Revision 4 to the YMP Systems Engineering Management Plan	Completely revised Systems Engineering Management Plan.	Open
Surface-Based Test Facilities Requirements Document, Rev. 1	Flows down changes made to Site Design and Test Requirements document by Change Request 94/266.	Open
Interim Change Notice 1 to Repository Design Requirements Document	Closes out two YMP Corrective Action Reports regarding caution about derived requirements.	Open
Interim Change Notice 1 to Engineered Barrier Design Requirements Document	Closes out two YMP Corrective Action Reports regarding caution about derived requirements.	Open

Note: TBD = To Be Determined
TBV = To Be Verified

Change Control Board Actions April 1, 1994 - September 30, 1994

Exploratory Studies Facility Changes

Title	Change Description	Status
Revised Exploratory Studies Facility Package 1A	Revises six and adds five new drawings for tunnel boring machine launch chamber design.	Closed
Revised Exploratory Studies Facility Technical Baseline	Adds new Summary Cost Estimate and Table of Contents.	Closed
Revised Exploratory Studies Facility Design Package 1A	Rolls up Field Change Requests and adds metric dimensions into 33 Package 1A drawings.	Closed
Deletion of "Explosive Storage Area" Drawings	Deletes three Exploratory Studies Facility drawings.	Closed
Revised Exploratory Studies Facility Design Package 1B	Revises eight electrical drawings to incorporate Field Change Requests.	Closed
Revised Exploratory Studies Facility Design Package 1A	Incorporates 17 Field Change Requests into 14 Exploratory Studies Facility drawings.	Closed
"Accept for Construction" Revise Booster Pump Station Building 7008	Revises nine drawings for acceptance for construction.	Closed
Revised Exploratory Studies Facility Cost Estimate	Reduces cost estimate for Integrated Data Control System and increases cost estimates for Topopah Spring Level North Ramp.	Closed
Revised Exploratory Studies Facility Package 1B	Revises 11 drawings to remove utility interferences.	Closed
"Accept for Construction" Revise Switchgear Building 5010	Revises 16 Exploratory Studies Facility configuration drawings for acceptance for construction.	Closed
Exploratory Studies Facility Configuration Item	Releases Exploratory Studies Facility configuration item identification chart that is compatible with Work Breakdown Structure 1.2.6 subelements.	Open

APPENDIX E

Study Plan Status as of September 30, 1994

Study Plan Status as of September 30, 1994 (Page 1 of 9)

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.2.1.1	Characterization of the Meteorology for Regional Hydrology	6/26/90	3/13/91	10/21/91	12/10/91
8.3.1.2.1.2	Characterization of Runoff and Streamflow	3/27/89	8/21/90	5/14/91	4/12/91
8.3.1.2.1.3	Characterization of the Regional Ground-Water Flow System	3/1/90	1/18/91	10/4/91	3/19/93
8.3.1.2.1.4	Regional Hydrologic System Synthesis and Modeling	6/6/90	12/18/91	5/6/92	1/29/93
8.3.1.2.2.1	Characterization of Unsaturated-Zone Infiltration	3/9/90	1/18/91	5/31/91	
8.3.1.2.2.2	Water Movement Test	9/23/87	11/9/89	4/8/93	
8.3.1.2.2.3	Characterization of Percolation in the Unsaturated Zone–Surface-Based Study	6/12/89	4/08/91	3/26/92	
8.3.1.2.2.4	Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility	9/8/87	1/09/89	3/5/93	
8.3.1.2.2.5	Diffusion Tests in the Exploratory Studies Facility	11/1/88	4/22/92	1/19/93	11/1/93
8.3.1.2.2.6	Characterization of Gaseous-Phase Movement in the Unsaturated Zone	6/12/89	6/11/91	10/07/91	5/1/92
8.3.1.2.2.7	Hydrochemical Characterization of the Unsaturated Zone	10/24/88	9/18/90	5/1/92	12/28/92
8.3.1.2.2.8	Fluid Flow in Unsaturated, Fractured Rock	9/7/90	8/12/92	1/28/93	
8.3.1.2.2.9	Site Unsaturated-Zone Modeling and Synthesis	1/25/91	7/1/93	11/8/93	

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Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.2.3.1	Characterization of the Site Saturated-Zone Ground-Water Flow System	2/8/88	2/22/90	12/6/91	
8.3.1.2.3.2	Characterization of the Saturated-Zone Hydrochemistry	3/28/90	4/22/92	1/4/93	
8.3.1.2.3.3	Saturated-Zone Hydrologic System Synthesis and Modeling	9/4/90	1/14/93	6/16/93	
8.3.1.3.1.1	Ground-Water Chemistry Model	3/15/91	8/4/94		
8.3.1.3.2.1	Mineralogy, Petrology, and Chemistry of Transport Pathway	1/22/88	6/13/89	8/20/90	12/28/92
8.3.1.3.2.2	History of Mineralogical and Geochemical Alteration of Yucca Mountain	3/28/88	12/18/91	4/27/92	1/24/94
8.3.1.3.3.1	Natural Analog of Hydrothermal Systems in Tuff	No Study Plan to be Developed			
8.3.1.3.3.2	Kinetics and Thermodynamics of Mineral Evolution	3/25/94			
8.3.1.3.3.3	Conceptual Model of Mineral Evolution				
8.3.1.3.4.1	Batch Sorption Studies	10/28/92	8/4/94		
8.3.1.3.4.2	Biological Sorption and Transport	12/12/88	11/25/92	3/25/93	
8.3.1.3.4.3	Development of Sorption Models	10/28/92	8/4/94		
8.3.1.3.5.1	Dissolved Species Concentration Limits	9/7/90	9/9/93		
8.3.1.3.5.2	Colloid Behavior	9/7/90	9/9/93		

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Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.3.6.1	Dynamic Transport Column Experiments	3/10/93			
8.3.1.3.6.2	Diffusion	7/24/89	8/6/93	1/19/94	
8.3.1.3.7.1	Retardation Sensitivity Analysis	12/14/88	8/11/92	1/19/93	
8.3.1.3.7.2	Demonstration of Applicability of Laboratory Data to Repository Transport Calculations	Out Year – Under Development			
8.3.1.3.8.1	Gaseous Radionuclide Transport Calculations and Measurements	No Study Plan to be Developed			
8.3.1.4.2.1	Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area	4/12/90	6/9/92	12/14/92	
8.3.1.4.2.2	Characterization of the Structural Features Within the Site Area	9/4/87	2/3/89	2/8/93	2/11/94
8.3.1.4.2.3	Three-Dimensional Geologic Model				
8.3.1.4.3.1	Systematic Acquisition of Site-Specific Subsurface Information	3/27/90	12/8/92	7/19/93	
8.3.1.4.3.2	Three-Dimensional Rock Characteristics Models	5/4/94			
8.3.1.5.1.1	Characterization of Modern Regional Climate	6/24/93	7/25/94		
8.3.1.5.1.2	Paleoclimate Study: Lake, Playa, and Marsh Deposits	10/25/90	10/31/91	4/27/92	1/24/94
8.3.1.5.1.3	Climatic Implications of Terrestrial Paleoecology	2/11/91	1/17/92	8/27/92	1/24/94

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Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.5.1.4	Analysis of the Paleoenvironmental History of the Yucca Mountain Region	3/30/90	5/29/91	12/06/91	1/11/93
8.3.1.5.1.5	Paleoclimate-Paleoenvironmental Synthesis	Out Year – Under Development			
8.3.1.5.1.6	Characterization of the Future Regional Climate and Environments	12/29/93	6/15/94		
8.3.1.5.2.1	Characterization of the Quaternary Regional Hydrology	1/26/88	6/8/89	11/24/89	4/9/91
8.3.1.5.2.2	Characterization of Future Regional Hydrology Due to Climate Changes	1/16/91	11/10/92	4/5/93	1/11/93
8.3.1.6.1.1	Distribution and Characteristics of Present and Past Erosion	No Study Plans to be Developed			
8.3.1.6.2.1	Influence of Future Climatic Conditions on Locations and Rates of Erosion				
8.3.1.6.3.1	Evaluation of the Effects of Future Tectonic Activity on Erosion at Yucca Mountain				
8.3.1.6.4.1	Development of a Topical Report on the Effects of Erosion				
8.3.1.8.1.1	Probability of Magmatic Disruption of the Repository	3/29/89	9/19/90	10/5/91	8/8/91
8.3.1.8.1.2	Physical Processes of Magmatism and Effects on the Repository	10/21/92	9/21/93	9/14/94	
8.3.1.8.2.1	Analysis of Waste Package Rupture Due to Tectonic Processes and Events	12/15/89	11/16/92	11/19/93	

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.8.2.1 R1	Tectonic Effects: Evaluations of Changes in the Natural and Engineered Barrier Systems Resulting from Tectonic Processes and Events	2/18/94			
8.3.1.8.3.1	Analysis of the Effects of Tectonic Processes and Events on Average Percolation Flux Rates Over the Repository	These Studies Have Been Combined Into 8.3.1.8.2.1 R1			
8.3.1.8.3.2	Analysis of the Effects of Tectonic Processes and Events on Changes in Water-Table Elevation				
8.3.1.8.3.3	Analysis of the Effects of Tectonic Processes and Events on Local Fracture Permeability and Effective Porosity				
8.3.1.8.4.1	Analysis of the Effects of Tectonic Processes and Events on Rock Geochemical Properties				
8.3.1.8.5.1	Characterization of Volcanic Features	12/14/88	4/18/90	8/20/90	2/21/91
8.3.1.8.5.2	Characterization of Igneous Intrusive Features	10/13/92	3/7/94	8/22/94	
8.3.1.8.5.3	Investigation of Folds in Miocene and Younger Rocks of the Region	No Study Plans to be Developed			
8.3.1.9.1.1	An Evaluation of Natural Processes that Could Affect the Long-Term Survivability of the Surface Marker System at Yucca Mountain				
8.3.1.9.2.1	Natural Resource Assessment of Yucca Mountain, Nye County, Nevada	7/13/90	11/6/92	3/16/93	2/11/94

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Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.9.2.2	Water Resource Assessment of Yucca Mountain, Nevada	10/6/89	8/26/91	5/4/92	12/28/92
8.3.1.9.3.1	Evaluation of Data Needed to Support an Assessment of the Likelihood of Future Inadvertent Human Intrusion at Yucca Mountain as a Result of Exploration and/or Extraction of Natural Resources	No Study Plans to be Developed			
8.3.1.9.3.2	An Evaluation of the Potential Effects of Exploration for, or Extraction of, Natural Resources on the Hydrologic Characteristics at Yucca Mountain				
8.3.1.12.2.1	Meteorological Data Collection at the Yucca Mountain Site	9/28/90	3/20/91	11/12/91	12/2/91
8.3.1.14.2	Studies to Provide Soil/Rock Properties of Potential Locations of Surface/Subsurface Facilities	7/15/91	10/01/91	1/24/92	4/6/92
8.3.1.15.1.1	Laboratory Thermal Properties	3/17/88	10/21/90	8/22/94	
8.3.1.15.1.2	Laboratory Thermal Expansion Testing	12/1/88	8/21/90	8/22/94	
8.3.1.15.1.3	Laboratory Determination of Mechanical Properties of Intact Rock	2/8/88	5/21/91	Deferred	
8.3.1.15.1.4	Laboratory Determination of the Mechanical Properties of Fractures	10/23/91			
8.3.1.15.1.5	Excavation Investigations	3/26/87	1/09/89	8/19/94	
8.3.1.15.1.6	In Situ Thermomechanical Properties	Out Year – Under Development			
8.3.1.15.1.7	In Situ Mechanical Properties				

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Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.15.1.8	In Situ Design Verification	3/20/90	2/3/93	4/15/93	11/1/93
8.3.1.15.2.1	Characterization of the Site Ambient Stress Conditions	Study Plan to be Cancelled and Decontrolled			
		9/22/87	1/11/89	Deferred	
8.3.1.15.2.2	Characterization of the Site Ambient Thermal Conditions	10/13/92	6/23/94		
8.3.1.16.1.1	Characterization of Flood Potential of the Yucca Mountain Site	3/30/89	9/17/90	5/8/91	1/22/91
8.3.1.16.2.1	Location of Adequate Water Supply for Construction, Operation, Closure, and Decommissioning of a Mined Geologic Disposal System at Yucca Mountain, Nevada	No Study Plan to be Developed			
8.3.1.16.3.1	Determination of the Preclosure Hydrologic Conditions of the Unsaturated Zone at Yucca Mountain, Nevada	Out Year – Under Development			
8.3.1.17.1.1	Potential for Ash Fall at the Site	No Study Plans to be Developed			
8.3.1.17.2.1	Faulting Potential at the Repository				
8.3.1.17.3.1	Relevant Earthquake Sources	8/1/90	12/18/91	5/18/92	1/13/93
8.3.1.17.3.2	Underground Nuclear Explosion Sources	Out Year – Under Development			
8.3.1.17.3.3	Ground Motion from Regional Earthquakes and Underground Nuclear Explosions	2/2/94	9/6/94		
8.3.1.17.3.4	Effects of Local Site Geology on Surface and Subsurface Motions	7/6/90	11/14/91	6/8/92	1/11/93

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Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.1.17.3.5	Ground Motion at the Site from Controlling Seismic Events	10/4/90	7/9/93	11/2/93	
8.3.1.17.3.6	Probabilistic Seismic Hazards Analyses	Out Year – Under Development			
8.3.1.17.4.1	Historical and Current Seismicity	10/17/89	9/17/90	5/14/91	11/1/93
8.3.1.17.4.2	Location and Recency of Faulting Near the Prospective Surface Facilities	12/6/88	5/22/89	11/24/89	5/29/90
8.3.1.17.4.3	Quaternary Faulting Within 100 km of Yucca Mountain, Including the Walker Lane	3/25/92	1/21/93	9/2/93	3/3/94
8.3.1.17.4.4	Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones	8/3/92	3/18/93	9/2/93	
8.3.1.17.4.5	Detachment Faults at or Proximal to Yucca Mountain	5/1/90	7/20/92	2/1/93	1/24/94
8.3.1.17.4.6	Quaternary Faulting Within the Site Area	10/14/88	1/23/91	10/3/91	1/13/93
8.3.1.17.4.7	Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain	No Study Plan to be Developed			
8.3.1.17.4.8	Stress Field Within and Proximal to the Site Area	Out Year – Under Development			
8.3.1.17.4.9	Tectonic Geomorphology of the Yucca Mountain Region	No Study Plan to be Developed			
8.3.1.17.4.10	Geodetic Leveling	3/30/90	1/18/91	10/4/91	2/1/93
8.3.1.17.4.11	Characterization of Regional Lateral Crustal Movement	No Study Plan to be Developed			
8.3.1.17.4.12	Tectonic Models and Synthesis	4/30/93			

Study Plan Number	Study Plan Title	Submitted to YMSCO[a]	Approved by YMSCO[b]	Reviewed by NRC[c]	Reviewed by NV[d]
8.3.3.2.2.1	Seal Material Properties Development	Out Year – Under Development			
8.3.3.2.2.3	In Situ Testing of Seal Components	9/16/94			
8.3.4.2.4.1	Characterization of the Chemical and Mineral Changes in the Postemplacement Environment	8/8/94			
8.3.4.2.4.2	Hydrological Properties of Waste Package Environment	12/20/93			
8.3.4.2.4.3	Characterization of the Geomechanical Attributes for the Waste Package Environment	6/28/89	12/11/92	4/21/93	
8.3.4.2.4.4	Engineered Barrier System Field Tests	7/9/93			
8.3.4.2.4.5	Effects of Man-Made Materials on Water Chemistry	4/28/94			

[a] Submitted to YMSCO and under review.
[b] Completed YMSCO review.
[c] Completed NRC initial review with no objections.
[d] Received comments from State of Nevada.

APPENDIX F

References

REFERENCES

Technical reports and research products published by participating organizations on the Project are available through the DOE Office of Scientific and Technical Information at Oak Ridge, Tennessee, which is the national center for dissemination of nonclassified scientific and technical information prepared from research sponsored by DOE. These documents may be ordered from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

The references cited in this section are also available for inspection at DOE public reading rooms in Nevada and Washington, D.C., the open literature, or through proceedings volumes for symposia and technical conferences. Annotated outlines of Project-sponsored reports can be found in the Project Bibliography, which is updated approximately every six months, and may be obtained through the Office of Scientific and Technical Information.

Akgun, H. and J. J. K. Daemen, 1989. Bond Strength of Cementitious Borehole Plugs in Welded Tuff, NUREG/CR-4295, Technical Report to the U. S. Nuclear Regulatory Commission, Division of Engineering Safety, Office of Nuclear Regulatory Research, Department of Mining and Geological Engineering, University of Arizona, Tucson, Arizona.

Anderson, L. and R. Klinger, in prep. Preliminary Evaluation of the Bare Mountain Fault Zone, Tarantula Canyon, Nye County, Nevada, submitted for publication in a USGS Circular, U.S. Geological Survey, Denver, Colorado.

Anderson and Su, in prep. Seismic Site Effects in the Vicinity of Yucca Mountain, Nevada, U.S. Geological Survey, Denver, Colorado.

Andrews, R. W., T. F. Dale, and J. A. McNeish, 1994. Total System Performance Assessment - 1993: An Evaluation of the Potential Yucca Mountain Repository, B00000000-01717-2200-00099, Revision 01, Civilian Radioactive Waste Management System Management and Operating Contractor, INTERA, Inc., Las Vegas, Nevada.

Barr, G. E., in prep. Scenarios Constructed for Nominal Flow in the Presence of a Repository at Yucca Mountain and Vicinity, SAND92-2186, Sandia National Laboratories, Albuquerque, New Mexico.

Beiling Liu, in prep. Cosmogenic ^{36}Cl [Chlorine-36] Dating of Geomorphic Surfaces and Isotopic Investigation of Soil Water and Paleoclimate, Ajo Mountain, Southern Arizona, U.S. Geological Survey, Denver, Colorado.

REFERENCES (Continued)

Bhattacharyya, K. K., 1994. Interoffice Correspondence from K. K. Bhattacharyya (Civilian Radioactive Waste Management System Management and Operating Contractor) to R. D. Memory (Civilian Radioactive Waste Management System Management and Operating Contractor), June 1, 1994, regarding vertical borehole emplacement-operations and quantity.

Bodvarsson, G. S., G. Chen, and C. Wittwer, 1994. "Preliminary Analysis of Three-Dimensional Moisture Flow within Yucca Mountain, Nevada," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 2038-2047.

Boucher, M. S., 1994. Precision and Accuracy of Manual Water-Level Measurements Taken in the Yucca Mountain Area, Nye County, Nevada, 1988-90, USGS-WRI-93-4025, Water Resources Investigations Report, U.S. Geological Survey, Denver, Colorado.

Boucher, M. S., in prep. Water Levels in Wells J-11 and J-12, 1989-91, in the Yucca Mountain Area, Nevada, U.S. Geological Survey, Denver, Colorado.

Braun, C. A. et al., in prep.[a]. Detailed Geologic Maps Along the Ghost Dance Fault, Yucca Mountain, Nevada, U.S. Geological Survey, Denver, Colorado.

Braun, C. A. et al., in prep.[b]. Geologic and Fracture Maps for the ARP-1 Exposure at Yucca Mountain, Nye County, Nevada, U.S. Geological Survey, Denver, Colorado.

Bullen, in prep. Survey of the Degradation Modes of Iron-Base, Corrosion-Allowance Materials, Iowa State University.

Burger and Scofield, in prep. Perched Water Occurrences and their Implications on the Exploratory Studies Facility, U.S. Geological Survey, Denver, Colorado.

Burns, R. G., V. M. Wood, and M. E. Morgenstein, 1992. "Sorption of Cesium and Strontium by Zeolite Single Crystals," UC-510, Lawrence Livermore National Laboratory, Livermore, California; also in Proceedings of the DOE/Yucca Mountain Site Characterization Project Radionuclide Adsorption Workshop at Los Alamos National Laboratory, September 11-12, 1990, J. A. Canepa (comp), LA-12325-C, Los Alamos, New Mexico, pp. 77-90.

REFERENCES (Continued)

Buscheck, T. A and J. J. Nitao, 1994. The Impact of Buoyant Gas-Phase Flow and Heterogeneity on Thermo-Hydrological Behavior at Yucca Mountain," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 2450-2474; also UCRL-JC-115351, Lawrence Livermore National Laboratory, Livermore, California.

Buscheck, T. A., J. J. Nitao, and S. F. Saterlie, 1994. "Evaluation of Thermo-Hydrological Performance in Support of the Thermal Loading Systems Study," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 2, pp. 592-610; also UCRL-JC-115352, Lawrence Livermore National Laboratory, Livermore, California.

Cardenas-Garcia and Severson, in prep. An Assessment of Optical, Non-Contact and Automated Experimental Techniques for Topographical Mapping of Object Surfaces, U.S. Geological Survey, Denver, Colorado.

Carey, J. W., and D. L. Bish, 1994. "Hydration Energetics of Zeolites," Abstract, 31st Annual Clay Minerals Society Meeting, University of Saskatchewan, Saskatoon, Saskatchewan, August 13-18, 1994.

Carlos, B. A. and Garcia, in prep. Field Guide to Fracture-lining Materials at Yucca Mountain, Nevada, Los Alamos National Laboratory, Los Alamos, New Mexico.

Carlos, B. A. et al., in prep. Distribution and Chemistry of Fracture-lining Minerals at Yucca Mountain, Nevada, Los Alamos National Laboratory, Los Alamos, New Mexico.

Castor, S. B. and C. D. Henry, 1993. Volcanic Rock-Hosted Uranium Mineralizations in Nevada and Oregon as Natural Analogues for the Potential Nuclear Waste Repository at Yucca Mountain, Nevada, written communication, Nevada Bureau of Mines and Geology, University of Nevada, Reno.

Chipera, S. J. and D. L. Bish, 1994. Quantitative X-ray Diffraction Results for Samples used for the Sorption Task, Los Alamos National Laboratory, Los Alamos, New Mexico.

Chipera, S. J. and D. L. Bish, in prep. Multi-reflection RIR and Intensity Normalizations for Quantitative Analyses: Applications to Feldspars and Zeolites, LA-EES-1-05-94-001, Los Alamos National Laboratory, Los Alamos, New Mexico.

Chipera, S. J., J. W. Carey, and D. L. Bish, 1994. "The Nature of Interlayer Water in Smectite," Abstract, 31st Annual Clay Minerals Society Meeting, University of Saskatchewan, Saskatoon, Saskatchewan, August 13-18, 1994.

REFERENCES (Continued)

Chipera, S. J. et al., in prep. Mineralogic Variation in Drill Core UE-25 UZ#16, Yucca Mountain, Nevada, Los Alamos National Laboratory, Los Alamos, New Mexico.

Ciesnik, M. S. et al., in prep. Basic Data Report on Core Experiments, U.S. Geological Survey, Denver, Colorado.

Conca, J. L. and I. R. Triay, 1994. "Selenite Transport in Unsaturated Tuff from Yucca Mountain," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 1275-1282.

Cromer, M. V. and C. A. Rautman, 1994a. Use of Stratigraphy as Soft Information to Contrast Stochastic Modeling of Rock Properties: An Interim Status Report, SLTR94-0003, Sandia National Laboratories, Albuquerque, New Mexico.

Cromer, M. V. and C. A. Rautman, 1994b. Development of the GSLIB/LYNX Integration Module (GLINTMOD): An Interim Status Report, SLTR94-0006, Sandia National Laboratories, Albuquerque, New Mexico.

Crowe, B. M. et al., in prep. Status of Volcanism Studies for the Yucca Mountain Site Characterization Studies," Los Alamos National Laboratory, Los Alamos, New Mexico.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1993a. Catalog of Planned Boreholes for Surface-Based Testing Site Characterization Activities, BAA000000-01717-3300-00002, Revision 0, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1993b. Site Characterization Activities Catalog, BA0000000-01717-3300-00003, Revision 0, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1993c. Yucca Mountain Site Characterization Project FY 1994 ESF Engineering Plan, B00000000-01717-4600-00023, Revision 01, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1993d. Waste Isolation Evaluation - Package 1A Sanitary Sewer System for the Exploratory Studies Facility, B00000000-01717-2200-00040, Revision 00, Las Vegas, Nevada.

REFERENCES (Continued)

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1994a. Initial Summary Report For Repository/Waste Package Advanced Conceptual Design, B00000000-01717-5705-00015, Revision 00, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1994b. Controlled Design Assumptions Document, B00000000-01717-4600-00032, Revision 00, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1994c. Definition of Repository Block Limits, BC0000000-01717-0200-00003, Revision 00, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1994d. Waste Package Performance Allocation Emplacement Mode System Study, B00000000-01717-5705-00018, Revision 00, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1994e. Thermal Loading System Study Interim Report, B00000000-01717-5705-00016, Revision 00, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1994f. Thermal Evaluations of Waste Package Emplacement, BBA000000-01717-4200-00008, Revision 00, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1994g. Spent Nuclear Fuel Assembly Thermal Model, BBA000000-01717-4200-00009, Revision 00, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1994h. Long-Term Criticality Control Considerations, BBA000000-01717-4200-00006, Revision 00, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1994i. Compilation and Review of Backfill Literature, BBB000000-01717-5705-00001, Revision 00, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1994j. Report of Preliminary RIP/YMIM Design Analyses, BBA000000-01717-5705-00002, Revision 01, Las Vegas, Nevada.

REFERENCES (Continued)

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1994k. Initial Review/Analysis of Thermal and Neutronic Characteristics of Potential MPC/WP Filler Materials, BBA000000-01717-5705-00001, Revision 00, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1994m. Retrievability Period Systems Study Report, B00000000-01717-5705-00017, Revision 0, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1994n. Additional Sensitivity Analyses Extending the Total System Performance Assessment (TSPA) - 1993 Results, B00000000-0717-0200-00122, Revision 00, Las Vegas, Nevada.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), in prep. FY 1995 Technical Implementation Plan for Each WBS Element, Yucca Mountain Site Characterization Project, Las Vegas, Nevada.

Czarnecki, J. B., 1994. "Automatic Editing and Graphical Postprocessing of Output from the MODular Finite Element (MODFE) Model in Proceedings of the U.S. Geological Survey National Computer Technical Meeting 1994; also OFR-94-52, Open-File Report, U.S. Geological Survey.

D'Agnese, F. A., in prep. A Regional Potentiometric Surface Map of the Death Valley Region, Nevada and California Using Interactive Gridding and Geographic Information System Techniques, U.S. Geological Survey, Denver, Colorado.

D'Agnese, F. A. et al., in prep. Preliminary Digital Geologic Maps of the Mariposa, Kingman, Trona, and Death Valley Sheets, California, U.S. Geological Survey, Denver, Colorado.

Daley, T. M., E. L. Majer, and E. Karageorgi, in prep. Analysis Paper: Combined Analysis of Surface Reflection Imaging and Vertical Seismic Profiling, Lawrence Berkeley Laboratory, Berkeley, California.

Dickerson, R. P. and R. W. Spengler, in prep. Structure of the Northern Part of the Paintbrush Canyon, Yucca Mountain, Nevada, U.S. Geological Survey, Denver, Colorado.

DOE (U.S. Department of Energy), 1986. Final Environmental Assessment: Yucca Mountain Site, Nevada Research and Development Area, Nevada, DOE/RW-0073, Office of Civilian Radioactive Waste Management, Washington, D.C.

REFERENCES (Continued)

DOE (U.S. Department of Energy), 1988. Site Characterization Plan: Yucca Mountain Site, Nevada Research and Development Area, Nevada, DOE/RW-0199, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE (U.S. Department of Energy), 1989. "General Design Criteria," DOE Order 6430.1, Office of Project and Facilities Management, Washington, D.C.

DOE (U.S. Department of Energy), 1990a. Project Management Plan, YMP/88-2, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1990b. Regulatory Compliance Plan, YMP/90-33, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1990c. Yucca Mountain Project Q-List, YMP/90-55, Revision 2, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1992a. Yucca Mountain Site Characterization Project Advance Acquisition or Assistance Plan, YMP/88-2A, Revision 1, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1992b. Configuration Management Plan, YMP/88-4, Revision 3, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1992c. Progress Report on the Scientific Investigation Program for the Nevada Yucca Mountain Site, Number 6, DOE/RW-0307P-6, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE (U.S. Department of Energy), 1992d. Quality Assurance Requirements and Description, DOE/RW/0333P, Revision 1, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE (U.S. Department of Energy), 1993a. Test and Evaluation Plan, YMP/90-22, Revision 1, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1993b. Evaluation of the Potentially Adverse Condition "Evidence of Extreme Erosion during the Quaternary Period" at Yucca Mountain, YMP/92-41-TPR, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1993c. Site Characterization Progress Report: Yucca Mountain, Nevada, Number 8, DOE/RW-0423, Office of Civilian Radioactive Waste Management, Washington, D.C.

REFERENCES (Continued)

DOE (U.S. Department of Energy), 1993d. Site Characterization Progress Report: Yucca Mountain, Nevada, Number 7, DOE/RW-0307P-7, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE (U.S. Department of Energy), 1993e. Yucca Mountain Site Characterization Project Tracers, Fluids, and Materials Management Plan, YMP/91-23, Revision 2, Yucca Mountain Site Characterization Officer, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1994a. Site Characterization Program Baseline, YMP/CM-0011, Revision 11, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1994b. Project Technical Implementation Plan Fiscal Year 1994, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE (U.S. Department of Energy), 1994c. Site Characterization Progress Report: Yucca Mountain, Nevada, Number 10, DOE/RW-0450, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE (U.S. Department of Energy), 1994d. Mined Geological Disposal System Requirements Document, DOE/RW-0404P, Revision 1, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE (U.S. Department of Energy), 1994e. Site Design and Test Requirements Document, YMP/CM-0021, Revision 1, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1994f. Exploratory Studies Facility Design Requirements, YMP/CM-0019, Revision 0, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1994g. Surface-Based Testing Facilities Requirements Document, YMP/CM-0022, Revision 1, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1994h. Safety and Health Plan, YMP/90-37, Revision 2, Yucca Mountain Site Characterization Project, Office of Civilian Radioactive Waste Management, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1994i. Work Breakdown Structure Index and Dictionary - Annex II to the Project Management Plan, YMP/CC-0001, Revision 12/2/94, Yucca Mountain Site Characterization Office, Las Vegas, Nevada,

REFERENCES (Continued)

DOE (U.S. Department of Energy), 1994j. Systems Engineering Management Plan, YMP/CC-0007, Revision 04, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1994k. OCRWM Systems Engineering Management Plan (SEMP), DOE/RW-0051, Revision 3, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE (U.S. Department of Energy), 1994m. Letter from D. A. Dreyfus, Office of Civilian Radioactive Waste Management to R. W. Fri (National Academy of Sciences), April 8, 1994, regarding radiation protection standards.

DOE (U.S. Department of Energy), 1994n. Topical Report YMP/TR-002-NP: Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1994o. Letter from D. E. Shelor (Office of Civilian Radioactive Waste Management System) to J. J. Holonich (U.S. Nuclear Regulatory Commission), March 30, 1994, providing a supplemental response to Site Characterization Analysis Comment 80.

DOE (U.S. Department of Energy), 1994p. Letter from D. E. Shelor (Office of Civilian Radioactive Waste Management System) to J. J. Holonich (U.S. Nuclear Regulatory Commission), May 17, 1994, providing a supplemental response to Site Characterization Analysis Comment 5 and Questions 3, 46, and 56.

DOE (U.S. Department of Energy), 1994q. Letter from D. E. Shelor (Office of Civilian Radioactive Waste Management System) to J. J. Holonich (U.S. Nuclear Regulatory Commission), June 10, 1994, providing a supplemental response to Site Characterization Analysis Question 47.

DOE (U.S. Department of Energy), 1994r. Letter from S. J. Brocoum (Office of Civilian Radioactive Waste Management System) to J. J. Holonich (U.S. Nuclear Regulatory Commission), September 20, 1994, providing a supplemental response to Site Characterization Analysis open items on Substantially Complete Containment.

DOE (U.S. Department of Energy), 1994s. Letter from D. E. Shelor (Office of Civilian Radioactive Waste Management) to J. J. Holonich (U.S. Nuclear Regulatory Commission), June 10, 1994, regarding a description of the general approach to calculation of ground-water travel time.

REFERENCES (Continued)

DOE (U.S. Department of Energy), 1994t. Letter from R. M. Nelson (Yucca Mountain Site Characterization Office) to Distribution, April 21, 1994, regarding the DOE position on the boundary of the Engineered Barrier System.

DOE (U.S. Department of Energy), 1994u. Letter from D. E. Shelor (Office of Civilian Radioactive Waste Management System) to J. J. Holonich (U.S. Nuclear Regulatory Commission), June 16, 1994, providing a supplemental response to Site Characterization Analysis Comment 36 and Questions 5 and 20.

DOE (U.S. Department of Energy), 1994v. Letter from D. E. Shelor (Office of Civilian Radioactive Waste Management System) to J. J. Holonich (U.S. Nuclear Regulatory Commission), July 1, 1994, providing a supplemental response to Site Characterization Analysis Questions 35, 45, and 51.

DOE (U.S. Department of Energy), 1994w. Yucca Mountain Project Management Control (MC)-List, YMP/93-17, Revision 1, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1994x. Site Environmental Report for Calendar Year 1993, Yucca Mountain Site, Nye County, Nevada, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), 1994y. Multi-Purpose Canister System Evaluation: A Systems Engineering Approach, DOE/RW-0445, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE (U.S. Department of Energy), 1994z. Waste Acceptance System Requirements Document, DOE/RW-0351P, Revision 1, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE (U.S. Department of Energy), in prep.[a] Yucca Mountain Site Characterization Project Five-Year Plan for Fiscal Years 1996-2000, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE (U.S. Department of Energy), in prep.[b] Civilian Radioactive Waste Management Program Plan, Vol. 1, Program Overview.

DOE (U.S. Department of Energy), in prep.[c] Environmental Management Plan, Yucca Mountain Site Characterization Project, Office of Civilian Radioactive Waste Management, Las Vegas, Nevada.

REFERENCES (Continued)

DOE (U.S. Department of Energy), in prep.[d] Mined Geologic Disposal System License Application Annotated Outline, Revision 0 (formerly entitled "Mined Geologic Disposal System Annotated Outline Skeleton Text for the Preparation of a License Application, Revision 4") YMP 94-05, Yucca Mountain Site Characterization Office, Las Vegas, Nevada.

DOE (U.S. Department of Energy), in prep.[e] Environmental Monitoring and Mitigation Plan Progress Report.

Dunn, E. and S. R. Sobolik, 1993. Evaluation of the Effects of Underground Water Usage and Spillage in the Exploratory Studies Facility," SAND93-1182, Sandia National Laboratories, Albuquerque, New Mexico.

Fabryka-Martin, J., G. S. Bodvarsson, S. Wightman, W. Murphy, M. Wickham, M. Caffee, G. Nimz, J. Southon, P. Sharma, 1994. "Distribution of Chlorine-36 in the Unsaturated Zone at Yucca Mountain: An Indicator of Fast Transport Paths," Abstract, Eighth International Conference on Geochronology, Cosmochronology, and Isotope Geology, Berkeley, California, June 5-11, 1994.

Fabryka-Martin, J., in prep. Infiltration Processes at Yucca Mountain Inferred from Chlorine-36 Distributions, Los Alamos National Laboratory, Los Alamos, New Mexico.

Faunt, C. C., in prep. Effects of Faulting on Ground Water Flow in the Death Valley Region, Nevada and California, U.S. Geological Survey, Denver, Colorado.

Faunt, C. C. et al., in prep. Hydrostratigraphy of the Death Valley Region, Nevada and California, U.S. Geological Survey, Denver, Colorado.

Fernandez, J. A., J. B. Case, and C. B. Carney, 1994. Strategy to Seal Exploratory Boreholes in Unsaturated Tuff, SAND93-1184, Sandia National Laboratories, Albuquerque, New Mexico.

Finley, R. E. et al., in prep.[a] Seal Component Testing for the Yucca Mountain Project FY94: Status and Impacts, SLTR94-0007, Sandia National Laboratories, Albuquerque, New Mexico.

Finley, R. E. et al., in prep.[b] A Sealing and Backfilling Strategy for the Proposed High-Level Waste Repository, SAND94-0645, Sandia National Laboratories, Albuquerque, New Mexico.

Flint, L. E., C. A. Rautman, and A. L. Flint, in prep. Physical and Hydrologic Properties of Rock Outcrop Samples at Yucca Mountain, Nevada, Open-File Report, U.S. Geological Survey, Denver, Colorado.

REFERENCES (Continued)

Forrester et al., in prep. Late Quaternary and Holocene Climate Derived from Vegetation History and Plant Cellulose Stable Isotope Records from the Great Basin of Western North America, U.S. Geological Survey, Denver, Colorado.

Fridrich, C. J., B. M. Crowe, M. R. Hudson, V. E. Langenheim, and G. A. Thompson, in prep. Structural Controls on Basaltic Volcanism in the Southwest, presented in an administrative report.

Gable et al., in prep. Site Scale Modeling of Radionuclide Transport at Yucca Mountain, NV: Grid Generation and Reactive Tracers, Los Alamos National Laboratory, Los Alamos, New Mexico.

Gansemer, J. D. and A. Lamont, 1994. "Identifying Significant Uncertainties in Thermally Dependent Processes for Repository Performance Analysis," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 2197-2206; also UCRL-JC-116315, Lawrence Livermore National Laboratory, Livermore, California.

Geldon, in prep. Results and Interpretations of Preliminary Aquifer Tests in Boreholes UE-25 c#1, UE-25 c#2, and UE-25 c#3, Yucca Mountain, Nye County, Nevada, U.S. Geological Survey, Denver, Colorado.

Geslin, J. K., and T. C. Moyer, in prep. Summary of Lithologic Logging of New and Existing Boreholes at Yucca Mountain, Nevada, March 1994 to June 1994, U.S. Geological Survey, Denver, Colorado.

Geslin, J. K., T. C. Moyer, and D. C. Buesch, in prep. Summary of Lithologic Logging of New and Existing Boreholes at Yucca Mountain, Nevada, August 1993 to February 1994, U.S. Geological Survey, Denver, Colorado.

Glass, R. J., V. C. Tidwell, A. L. Flint, W. Peplinski, and Y. Castro, 1994. "Fracture-Matrix Interaction in Topopah Spring Tuff: Experiment and Numerical Analysis," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 1905-1914; also SAND94-0443C, Sandia National Laboratories, Albuquerque, New Mexico.

Grambow, B., L. O. Werme, R. S. Forsyth, and J. Bruno, 1990. "Constraints by Experimental Data for Modeling of Radionuclide Release from Spent Fuel," in Materials Research Society Symposium Proceedings, Pittsburg, Pennsylvania: MRS: 176: pp. 465-474.

REFERENCES (Continued)

Gray, W. and L. Thomas, 1993. "Initial Results from Dissolution Testing of Various Air-Oxidized Spent Fuels," Materials Research Society Fall Meeting, Boston, Massachusetts, November 29-December 3, 1993; also PNL SA-22576, Pacific Northwest Laboratory, Richland, Washington.

Grisak, G. E. and J. F. Pickens, 1980. "Solute Transport Through Fractured Media. 1: The Effect of Matrix Diffusion," Water Resources Research, Vol. 16, No. 4, pp. 719-730.

Gross and Jaume, in prep. Historical Seismicity in the Southern Great Basin, USGS Administrative Report, U.S. Geological Survey, Denver, Colorado.

Guertal, W. R. et al., in prep. "Defining a Maximum Effective Particle Diameter for Hydrologic Characterization of Skeletal Soil," submitted for presentation at the Soil Science Society of America Meeting, November, 1994.

Guthrie, G. D., Jr. et al., in prep. Distribution of Potentially Hazardous Phases in the Subsurface at Yucca Mountain, Nevada, Los Alamos National Laboratory, Los Alamos, New Mexico.

Harrington, C., J. Whitney, A. J. T. Jull, and W. Phillips, in prep. Implications of Surface-Exposure Dating of Scarps along the Solitario Canyon and Windy Wash Faults, Yucca Mountain, Nevada, by In Situ-Produced Cosmogenic C-14, Los Alamos National Laboratory, Los Alamos, New Mexico.

Hawley, M. E. and P. S. Z. Rogers, 1994. "Iron Oxide Mineral-Water Interface Reactions Studied by AFM," Abstract, Scanning Microscopy International 1994 Meeting, Toronto, Canada, May 7-12, 1994.

Hevesi, J.A., D. S. Ambos, and A. L. Flint, 1994. "A Preliminary Characterization of the Spatial Variability of Precipitation at Yucca Mountain, Nevada, in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 2520-2529.

Higgins et al., in prep. Development of the One-Dimensional Compression Method for Extraction of Pore Water from Unsaturated Tuff, U.S. Geological Survey, Denver, Colorado.

Ho, C. K. and R. R. Eaton, in prep. Studies of the Thermohydrologic Flow Processes Using TOUGH2, SAND94-2011, Sandia National Laboratories, Albuquerque, New Mexico.

REFERENCES (Continued)

Ho, C. K., K. S. Maki, and R. J. Glass, 1994. "Studies of Non-Isothermal Flow in Saturated and Partially Saturated Porous Media," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 2481-2491; also SAND93-4045C, Sandia National Laboratories, Albuquerque, New Mexico.

Hobart et al., in prep.[a]. Comparison of Solubilities and Speciations from Oversaturation and undersaturation Experiments of Neptunium, Plutonium, and Americium in UE-25 p#1 Well Water at 60°C from the Yucca Mountain Region, Los Alamos National Laboratory, Los Alamos, New Mexico.

Hobart et al., in prep.[b]. Solubilities and Speciations from Oversaturation Experiments of Neptunium, Plutonium, and Americium in a Neutral Electrolyte with a Total Carbonate Similar to UE-25 p#1 Well Water from the Yucca Mountain Region, Los Alamos National Laboratory, Los Alamos, New Mexico.

Hofmann, L. L. et al., in prep. Development and Testing of Techniques to Obtain Infiltration Data for Unconsolidated Surface Materials, Yucca Mountain Area, Nye County, Nevada, U.S. Geological Survey, Denver, Colorado.

Hoisch, T., in prep. Conditions of Metamorphism at Bare Mountain, Nevada: Implications for Extensional Faulting, submitted for publication in a USGS Circular, U.S. Geological Survey, Denver, Colorado.

Holland, J. F. and J. Pott, in prep. Test Interference Calculations for the Yucca Mountain Project ESF Thermomechanical Experiments, SAND94-0278, Sandia National Laboratories, Albuquerque, New Mexico.

Hopkins, P. L., G. Yeh, M. D. Siegel, S. L. Carpenter, D. B. Ward, in prep. Evaluation and Development of LEHGC, a Hybrid Lagrangian-Eulerian Model of Hydro-GeoChemical Transport, Sandia National Laboratories, Albuquerque, New Mexico.

Hudson, D. et al., in prep. "Numerical Modeling of a Field Scale Ponded Infiltration Experiment," Abstract, submitted for presentation at the Soil Science of America Meeting, November, 1994.

Ijiri, Y. and K. Karasaki, 1994. "A Lagranian-Eulerian Finite-Element Method with Adaptive Gridding for Advection-Dispersion Problems," in Proceedings of the Tenth International Conference on Computational Methods in Water Resources, Heidelberg, Germany, July 19-22, 1994; also LBL-35224, Lawrence Berkeley Laboratory, Berkeley, California.

REFERENCES (Continued)

Istok, J. D., C. A. Rautman, L. E. Flint, and A. L. Flint, 1994. "Spatial Variability in Hydrologic Properties of a Volcanic Tuff" Ground Water, Vol. 32, No.5, pp. 751-60.

Janecky and Duffy, in prep. Letter Report on Thermochemical Data on Actinides, Los Alamos National Laboratory, Los Alamos, New Mexico.

Johnstone, J. K., G. R. Gadley, and D. R. Waymire, 1985. In-Situ Tuff Water Migration/Heater Experiment: Final Report, SAND81-1918, Sandia National Laboratories, Albuquerque, New Mexico.

Kane, T. G., D. J. Bauer, and C. M. Martinez, 1994. Streamflow and Selected Precipitation Data for Yucca Mountain Region, Southern Nevada and Eastern California, Water Years 1986-90, OFR-94-312, Open-File Report, U.S. Geological Survey, Carson City, Nevada.

Kessel, D., C. E. Brechtel, and G. Norris, in prep. Geoengineering Characterization of Nonlithified Tuffs to be Encountered by the North Ramp West of the Bow Ridge Fault, SLTR94-0001, Sandia National Laboratories, Albuquerque, New Mexico.

King, G. and R. Janssen, in prep. Tectonic Modeling at Yucca Mountain, Nye County, Nevada, submitted for publication in a USGS Circular, U.S. Geological Survey, Denver, Colorado.

Klinger, R. and L. Piety, in prep. "Late Quaternary Slip Rate Estimates for the Death Valley and Furnace Creek Faults, Death Valley, California," U.S. Geological Survey, Denver, Colorado, for presentation at the 1994 Geological Society of America Annual Meeting.

Kohler et al., in prep.[a]. Uranyl Interactions in the Goethite Solution Interface Region: Formation of Binary and Ternary Surface Comlexes," Los Alamos National Laboratory, Los Alamos, New Mexico.

Kohler et al., in prep.[b]. Neptunium(V) Sorption on Hematite in Aqueous Suspension: Effects of Carbonate and EDTA, Los Alamos National Laboratory, Los Alamos, New Mexico.

Kung, S. and I. Triay, in prep. The Effect of Organic Coatings on Radionuclide Sorption, Los Alamos National Laboratory, Los Alamos, New Mexico.

Kwicklis, E. M., A. L. Flint, and R. W. Healy, 1994. "Simulation of Flow in the Unsaturated Zone Beneath Pagany Wash, Yucca Mountain, in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 2341-2351, American Nuclear Society, LaGrange Park, Illinois.

REFERENCES (Continued)

Lamont, A. D., in prep. "Integrated Modeling of Near Field and Engineered Barrier System Processes," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 3, pp. 1195-1201; also UCRL-JC-115230, Lawrence Livermore National Laboratory, Livermore, California.

Leckie, J. et al., in prep. Sorption by Surface Complexation onto Devitrified Tuffs, Los Alamos National Laboratory, Los Alamos, New Mexico.

Levy, S., in prep.[a] Studies of Altered and Fractured Rocks exposed around Yucca Mountain, Nevada, Los Alamos National Laboratory, Los Alamos, New Mexico.

Levy, S. in prep.[b] Technical Report on the Origin of Calcite-Silica Deposits at Trench 14 and Busted Butte and Methodologies Used to Determine Their Origin, Los Alamos National Laboratory, Los Alamos, New Mexico.

Levy, S., in prep.[c] Chemical-Textural Studies of Element Mobility During Zeolitization, Los Alamos National Laboratory, Los Alamos, New Mexico.

Levy, S. and G. Valentine, 1994. "Natural Alteration in the Cooling Topopah Spring Tuff, Yucca Mountain, Nevada, as an Analog to a Waste-Repository Hydrothermal Regime," in Proceedings of the Topical Meeting on Site Characterization and Model Validation, FOCUS '93, Las Vegas, Nevada, September 26-39, 1993, American Nuclear Society, La Grange Park, Illinois, pp. 145-149,

Lewis, L. C. and M. L. Wilson, 1994. "On Integrating Modeling Software for Application to Total System Performance Assessment," SPECTRUM '94 Conference, Atlanta, Georgia, August 14-18, 1994, American Nuclear Society, La Grange Park, Illinois; also UCRL-JC-115613, Lawrence Livermore National Laboratory, Livermore, California.

Longenbaugh, R., C. A. Rautman, E. E. Ryder, C. S. Chocas, in prep. Yucca Mountain Thermal Response: An Evaluation of the Effects of Modeled Geologic Structure and Thermal Property Description, SAND94-2247, Sandia National Laboratories, Albuquerque, New Mexico.

Longenbaugh, R. S., E. E. Ryder, R. E. Finley, T. George, and C. K. Ho, in prep. Crushed Tuff Thermal Properties: Experimental and Numerical Results for a Bench-Scale Test, SAND94-2320, Sandia National Laboratories, Albuquerque, New Mexico.

Lu, Ning, 1994. "A Semianalytical Method of Path Line Computation for Transient Finite-Difference Groundwater Flow Models," Water Resources Research, Vol. 30, No. 8, pp. 2449-2459.

REFERENCES (Continued)

Luckey, R. R. et al., in prep. Conceptual Model of the Saturated-Zone Flow System at Yucca Mountain, Nevada, U.S. Geological Survey, Denver, Colorado.

Lundstrom, S.C. and R. G. Warren, 1994. "Late Cenozoic evolution of Fortymile Wash: major change in drainage pattern in the Yucca Mountain, Nevada region during late Miocene volcanism," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 2121-2130

Lundstrom, S. C. et al., in prep. Preliminary Surficial Deposits Map of the Northeast Quarter of the Busted Butte 7.5-foot Quadrangle," U.S. Geological Survey, Denver, Colorado.

Mahan, S. A. and R. J. Moscati, 1994 (in press). "Sr, O, and H Isotopes as Tracers of Regional Ground Water Flow through the Spring Mountains to Ash Meadows, SW Nevada," Abstract, Geological Society of America Meeting, Seattle, Washington, October 24-27, 1994.

Mansure, A. J. and T. S. Ortiz, 1984. Preliminary Evaluation of the Subsurface Area Available for a Potential Nuclear Waste Repository at Yucca Mountain, SAND84-0175, Sandia National Laboratories, Albuquerque, New Mexico.

Marshall, B. D. and S. A. Mahan, 1994. "Strontium Isotope Geochemistry of Soil and Playa Deposits near Yucca Mountain, Nevada," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4. pp. 2685-2691.

Marshall, B. D., Z. E. Peterman, and J. S. Stuckless, 1994. "Paleohydrology from strontium isotopes at Yucca Mountain, Nevada." Abstract, Eighth International Conference on Geochronology, Cosmochronology and Isotope Geology, Berkeley, California, June 5-11, 1994; also U.S. Geological Survey Circular 1107, p. 203.

McConnaughey, T. A., J. F. Whelan, K. P. Wickland, and R. J. Moscati, 1994. "Isotopic studies of Yucca Mountain soil fluids and carbonate pedogenesis," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 2584-2589.

McCoy, J. K., 1994a. Interoffice Correspondence from J. K. McCoy (Civilian Radioactive Waste Management System Management and Operating Contractor) to D. Stahl (Civilian Radioactive Waste Management System Management and Operating Contractor), August 5, 1994, regarding corrosion model for corrosion-allowance materials.

REFERENCES (Continued)

McCoy, J. K., 1994b. Interoffice Correspondence from J. K. McCoy (Civilian Radioactive Waste Management System Management and Operating Contractor) to A. O. Thompson (Civilian Radioactive Waste Management System Management and Operating Contractor), May 9, 1994, regarding issue evaluation WPD-001.

McKenna, S. A. and C. A. Rautman, in prep. Summary Evaluation of Yucca Mountain Surface Transects with Implications for Downhole Sampling, SAND94-2038, Sandia National Laboratories, Albuquerque, New Mexico.

Meijer, A., in prep. Ground Water Compositional Parameters Most Critical to the Sorption Behavior of Radionuclides of Concern to the Yucca Mountain Project, Los Alamos National Laboratory, Los Alamos, New Mexico.

Miller, W., R. Alexander, N. Chapman, I. McKinley and J. Smellie, 1994. "Natural Analogue Studies in the Geological Disposal of Radioactive Wastes," Studies in Environmental Science 57, Elsevier, Amsterdam, the Netherlands.

Moscati, R. J. and J. F. Whelan, 1994 (in press). "Stable Isotope Compositions and Formation Temperatures of Secondary Silica Mineralization from Pedogenic, Drill Core, and Hydrothermal Samples near Yucca Mountain, NV," Abstract, Geological Society of America Meeting, Seattle, Washington, October 24-27, 1994.

Moyer, T. C. and J. K. Geslin, in prep. Lithostratigraphy of the Calico Hills Formation and Prow Pass Tuff (Crater Flat Group) in the Vicinity of Yucca Mountain, Nevada, U.S. Geological Survey, Denver, Colorado.

NAS (National Academy of Science-National Research Council), 1983. Board on Radioactive Waste Management-Waste Isolation System Panel, A Study of the Isolation System for Geologic Disposal of Radioactive Wastes, National Academy Press, Washington, D.C.

NAS (National Academy of Science-National Research Council), 1990. Rethinking High-Level Radioactive Waste Disposal, a Position Statement of the Board on Radioactive Waste, National Academy Press, Washington, D.C.

Nelson, P. H., in prep. Preliminary WT/UZ Magnetometer and Magnetic Susceptibility Results at Boreholes UE-25 UZ#16, USW NRG-6 and USW WT-2, U.S. Geological Survey, Denver, Colorado.

NEPA (National Environmental Policy Act of 1969, as amended) 1969. 42 U.S.C. 4321 et seq.

REFERENCES (Continued)

Neymark, L. A., B. D. Marshall, L. M. Kwak, K. Futa, and S. A. Mahon, in prep. Geochemical and Pb, Sr, and O Isotopic Study of the Tiva Canyon Tuff and Topopah Spring Tuff in the Vicinity of Yucca Mountain, Nye County, Nevada, Open-File Report, U.S. Geological Survey, Denver, Colorado.

Nicholl, M. J. and R. J. Glass, 1994. "Wetting Phase Permeability in a Partially Saturated Horizontal Fracture," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois; also SAND94-2774C, Sandia National Laboratories, Albuquerque, New Mexico.

Nitsche, H., R. C. Gatti, E. M. Standifer, S. C. Lee, A. Mueller, T. Prussin, R. S. Deinhammer, H. Maurer, K Becraft, S. Leung, and S. A. Carpenter, 1992. Measured Solubilities and Speciations of Neptunium, Plutonium, and Americium in a Typical Groundwater (J-13) from the Yucca Mountain Region, LBL-30958, Lawrence Berkeley Laboratory, Berkeley, California..

NRC (U.S. Nuclear Regulatory Commission), 1989. NRC Staff Site Characterization Analysis of the U.S. Department of Energy's Site Characterization Plan, Yucca Mountain, Nevada, NUREG-1347, Office of Nuclear Material Safety and Safeguards, Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission), 1994a. Letter from J. J. Holonich (U.S. Nuclear Regulatory Commission) to R. A. Milner (Office of Civilian Radioactive Waste Management), August 22, 1994, regarding Commission staff review of the Department of Energy Extreme Erosion Topical Report.

NRC (U.S. Nuclear Regulatory Commission), 1994b. Letter from M. J. Bell (U.S. Nuclear Regulatory Commission) to R. A. Milner (Office of Civilian Radioactive Waste Management), September 7, 1994, regarding Commission staff acceptance review of the Seismic Hazards Topical Report.

NRC (U.S. Nuclear Regulatory Commission), 1994c. Letter from J. J. Holonich (U.S. Nuclear Regulatory Commission) to D. E. Shelor (Office of Civilian Radioactive Waste Management), February 28, 1994, regarding transmittal of the "Topical Report Review Plan."

NRC (U.S. Nuclear Regulatory Commission), 1994d. Letter from J. J. Holonich (U.S. Nuclear Regulatory Commission) to D. E. Shelor (Office of Civilian Radioactive Waste Management), July 11, 1994, regarding Commission staff comments on Site Characterization Analysis Comment 5 and Question 46.

REFERENCES (Continued)

NRC (U.S. Nuclear Regulatory Commission), 1994e. Letter from J. J. Holonich (U.S. Nuclear Regulatory Commission) to R. A. Milner (Office of Civilian Radioactive Waste Management), August 23, 1994, regarding the DOE proposed approach for demonstrating compliance with 10 CFR 60.113(a)(2).

NRC (U.S. Nuclear Regulatory Commission), 1994f. Letter from J. J. Holonich (U.S. Nuclear Regulatory Commission) to D. E. Shelor (Office of Civilian Radioactive Waste Management), June 21, 1994, regarding Commission staff comments on Site Characterization Analysis Comment 123.

NRC (U.S. Nuclear Regulatory Commission), 1994g. Letter from M. Federline (U.S. Nuclear Regulatory Commission) to R. A. Milner (Office of Civilian Radioactive Waste Management), September 26, 1994, regarding Commission staff evaluation closing Question 1 from Progress Report #6 and #7.

NWPA (Nuclear Waste Policy Act), 1983. "Nuclear Waste Policy Act of 1982," Public Law 97-425, 42 U.S.C. 10101-10226, Washington, D.C.

NWPAA (Nuclear Waste Policy Amendments Act), 1987. "Amendments to the Nuclear Waste Policy Act of 1982," Public Law 100-203, December 22, 1987, 100th Congress, Title V, pp. 236-266, Washington, D.C.

O'Brien, G. M. et al., in prep. Water Levels in the Yucca Mountain Area, Nevada, 1992," U.S. Geological Survey, Denver, Colorado.

O'Connell, W. J., T. S. Ueng, M. L. Lewis, 1993. Post-Closure Performance Assessment of Waste Packages for the Yucca Mountain Project, UCRL-ID-111979, Lawrence Livermore National Laboratory, Livermore, California.

O'Connell, W. J., T. S. Ueng, and L. C. Lewis, 1994. "Performance Assessment Model of a Single Waste Package" in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 3, pp. 1188-1194; also UCRL-JC-114699, Lawrence Livermore National Laboratory, Livermore, California.

O'Leary, D. W., in prep. Tectonic Significance of the Rock Valley Fault Zone, Nevada Test Site, prepared for publication as a USGS Circular, U.S. Geological Survey, Denver, Colorado.

REFERENCES (Continued)

Paces, J. B., C. M. Menges, B. L. Widmann, J. R. Wesling, C. A. Bush, K. Futa, H. T. Millard, P. B. Maat, and J. W. Whitney, 1994. "Preliminary U-Series Disequilibrium and Thermoluminescence Ages of Surficial Deposits and Paleosols Associated with Quaternary Faults, Eastern Yucca Mountain, in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 2391-2401.

Paces, J.B., S. A. Mahan, L. Kwak, L. A. Neymark, T. A. McConnaughey, and C. A. Bush, in prep. Preliminary age estimates for late Pleistocene ground-water discharge deposits near Yucca Mountain, Nevada, Open-File Report, U.S. Geological Survey, Denver, Colorado.

Pearcy, E. C. and W. M. Murphy, 1991. Geochemical Natural Analogs Literature Review, CNWRA 90-008, Center for Nuclear Waste Regulatory Analysis, San Antonio, Texas.

Pearcy, E. C., W. M. Murphy, R. T. Green, B. W. Leslie and J. D. Prikryl, 1993. NRC High-Level Radioactive Waste Research at CNWRA, Calendar Year 1991, Chapter 7, "Geochemical Natural Analogs, NUREG/CR-5817, CNWRA 91-01A, Vol. 2, Center for Nuclear Waste Regulatory Analysis, San Antonio, Texas.

Perfect et al., in prep. Hydrochemical Data Base for the Death Valley Region, California and Nevada, OFR-99-305, Open-File Report, U.S. Geological Survey, Denver, Colorado.

Perry, F. V. and B. M. Crowe, 1987. Preclosure Volcanic Effects: Evaluation for a Potential Repository Site at Yucca Mountain, Nevada, TWS-INC7-2/87-01, Los Alamos National Laboratory, Los Alamos, New Mexico.

Perry, F. V. and K. T. Straub, in prep. Geochemistry of the Lathrop Wells Volcanic Center, Los Alamos National Laboratory, Los Alamos, New Mexico.

Perry, F. V. et al., 1994a. Progress Report on Geochronology Studies, letter report, Los Alamos National Laboratory, Los Alamos, New Mexico.

Perry, F. V., B. M. Crowe, S. G. Wells, and L. D. McFadden, 1994b. "Field, Geochemical and Geochronologic Evidence for Polycyclic Volcanism at the Lathrop Wells Volcanic Center, Southwestern Nevada," Abstract, Eighth International Conference on Geochronology, Cosmochronology, and Isotope Geology, Berkeley, California, June 5-11, 1994.

Peterman, Z. E. and J. S. Stuckless, 1994. "Strontium Isotope Characterization of Flow Systems in Southern Nevada," USA Mineralogical Magazine, Vol. 58A, pp. 711-712.

REFERENCES (Continued)

Peterman, Z. E. and K. Futa, in prep. Geochemistry of Core Samples of the Tiva Canyon Tuff from Drillhole UE-25 NRG#3, U.S. Geological Survey, Denver, Colorado.

Peterman, Z. E., B. L. Widmann, B. D. Marshall, J. N. Aleinikoff, K. Futa, and S. A. Mahan, 1994. "Isotopic Tracers of Gold Deposition in Paleozoic Limestones, Southern Nevada," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 3, pp. 1316-1323.

Peterman, Z. E. et al., in prep. Geochemistry of Outcrop Samples from the Raven Canyon and Paintbrush Canyon Reference Sections, Yucca Mountain, Nevada, Open-File Report, U.S. Geological Survey, Denver, Colorado.

Piety, L., in prep. Preliminary Compilation of Known and Suspected Quaternary Faults within 100 km of Yucca Mountain, Open-File Report, U.S. Geological Survey, Denver, Colorado.

Pincus, H. J., in prep. Interlaboratory Testing Program for Rock Properties - Round Two - Confined Compression: Elastic Modulus and Ultimate Strength, prepared for the American Society for Testing and Materials/Institute for Standards Research.

PNL (Pacific Northwest Laboratory), in prep. Software Design Description for the AREST-CT Code Development, Richland, Washington.

Pott, J., J. Grant, and S. Carlisle, 1994. "Design Verification Activities in the Exploratory Studies Facility Starter Tunnel at Yucca Mountain," North American Tunneling conference and Exhibition, Denver, Colorado, 1994; also SAND94-0712C, Sandia National Laboratories, Albuquerque, New Mexico.

Price, R. H., R. J. Martin III, P. J. Boyd, and G. N. Boitnott, in prep. "Mechanical and Bulk Properties of Intact Rock Collected in the Laboratory in Support of the Yucca Mountain Site Characterization Project," accepted for presentation at the Workshop on Rock Mechanics Issues in Repository Design and Performance Assessment, Rockville, Maryland, September 19-20, 1994; also SAND94-2243C, Sandia National Laboratories, Albuquerque, New Mexico.

Pruess, K. and Y. Tsang, 1994. Thermal Modeling for a Potential High-Level Nuclear Waste Repository at Yucca Mountain, LBL-35381, Lawrence Berkeley Laboratory, Berkeley, California.

Rattray, G. et al., in prep. Adsorption of Sulfur Hexafluoride onto Crushed Volcanic Tuffs from Yucca Mountain, Nevada, U.S. Geological Survey, Denver, Colorado.

REFERENCES (Continued)

Rautman, C. A. and M. V. Cromer, 1994. Advances in Geostatistical Research by the Stanford Center for Reservoir Forecasting, SLTR94-0004, Sandia National Laboratories, Albuquerque, New Mexico.

Rautman, C. A. and T. H. Robey, 1994. "Development of Stochastic Indicator Model of Lithology, Yucca Mountain, Nevada," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 2510-2519; also SAND94-0155C, Sandia National Laboratories, Albuquerque, New Mexico.

Rautman, C. A., L. E. Flint, and A. L. Flint, in prep. Physical and Hydrologic Properties of Outcrop Samples from a Nonwelded to Welded Tuff Transition, Yucca Mountain, Nevada, SAND94-1440, Sandia National Laboratories, Albuquerque, New Mexico.

Raymond, R., S. J. Chipera, D. T. Vaniman, and B. A. Carlos, 1994. Silica Mobility in Devitrified Paintbrush Tuff, Yucca Mountain, Nevada, LA-EES-1-06-94-008, Los Alamos National Laboratory, Los Alamos, New Mexico.

RCRA (Resource Conservation and Recovery Act of 1976, as amended) 1976. PL 94-580; 42 U.S.C. 6901-6987.

Reimus, P. W. et al., in prep. Simultaneous Transport of Synthetic Colloids and a Nonsorbing Solute through Single Saturated Natural Fractures, Los Alamos National Laboratory, Los Alamos, New Mexico.

Renders et al., in prep. Precipitation and Dissolution Rate Constants for Cristobalite at 150° 300RC, Los Alamos National Laboratory, Los Alamos, New Mexico.

Riggs, A. C. et al., in prep. Long-Term Meteorological Data from Three Elevations at One Site in Organ Pipe Cactus National Monument, Arizona, August 1992 through March 1994, U.S. Geological Survey, Denver, Colorado.

Robey, T. H., in prep. Development of Models for Fast Fluid Pathways Through Unsaturated Heterogeneous Porous Media, SAND93-7109, Sandia National Laboratories, Albuquerque, New Mexico.

Roedder, E., J. F. Whelan, and D. T. Vaniman, 1994. "Fluid Inclusion Crushing Studies of Calcite Veins from Yucca Mountain, Nevada, Tuffs: Environment of Formation," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 1854-1860.

REFERENCES (Continued)

Ryder, E. E. and J. Holland, 1994. Near-Field Thermal Analyses in Support of the M&O's FY93 Thermal Loading Systems Study," SLTR94-0005, Sandia National Laboratories, Albuquerque, New Mexico.

Savard, C. S., in prep. Selected Hydrologic Data from Fortymile Wash in the Yucca Mountain Area, Nevada, Water Year 1992," U.S. Geological Survey, Denver, Colorado.

Savard, C. S. and D. A. Beck, in prep. "Transmission Losses in Fortymile Wash near Yucca Mountain, Nevada," submitted for presentation at the American Geophysical Union 1994 Fall Meeting.

Scott, R. B., and J. Bonk, 1984. Preliminary Geologic Map of Yucca Mountain, Nye County, Nevada, with Geologic Sections, Map USGS-OFR-84-494, Open-File Report, U.S. Geological Survey, Denver, Colorado.

Sharpe, S. E., J. F. Whelan, R. M. Forester, and T. A. McConnaughey, 1994. "Molluscs as climate indicators: Preliminary results of stable isotope and species analysis," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois,Vol. 4, pp. 2538-2544.

Shi, G. H. and R. E. Goodman, 1985. "Two Dimensional Discontinuous Deformation Analysis," International Journal for Numerical and Analytical Methods in Geomechanics, Vol. 9, pp. 541-556.

Shibata, T. and T. Takeyama, 1977. "Stochastic Theory of Pitting Corrosion," Corrosion, Vol. 33, p. 243.

Shibata, T. and T. Takeyama, 1980. "Pitting Potential as a Function of Potential Sweep Velocity," in Proceedings Second Japan-U.S.S.R. Corrosion Seminar, JSCE, p. 178.

Sikora, R. F. et al., in prep. Preliminary Report on Aeromagnetic Surveys Along Trace of Seismic Profiles Across Crater Flat and Parts of Yucca Mountain, Nevada," U.S. Geological Survey, Denver, Colorado.

Simonds, B., in prep.[a]. Geology and Hydrothermal Alteration at the Calico Hills, Nye County, Nevada, U.S. Geological Survey, Denver, Colorado.

Simonds, B., in prep.[b]. The Miocene/Paleozoic Contact at the Calico Hills, Nye County, Nevada, submitted for publication in a USGS Circular, U.S. Geological Survey, Denver, Colorado.

REFERENCES (Continued)

Simonds, B. in prep.[c]. Evaluation of Postulated Detachment Faults in the Specter Range and Camp Desert Rock Areas, U.S. Geological Survey, Denver, Colorado.

Simonds, B, in prep.[d]. Geology and Hydrothermal Alteration at the Calico Hills, Nye County, Nevada, U.S. Geological Survey, Denver, Colorado.

Simonds, B. et al., in prep. Map of Fault Activity in the Yucca Mountain Area, Nye County, Nevada, MI-2520, submitted for publication as a Miscellaneous Investigations Series report, U.S. Geological Survey, Denver, Colorado.

Singer, F. R., R. P. Dickerson, and M. J. Olsten, in prep. Geochemistry of Borehole Samples from USW G-1 and USW GU-3/G-3, Yucca Mountain, Nevada, U.S. Geological Survey, Denver, Colorado.

Sobolik, S. R. and M. E. Fewell, 1992. Estimation of the Impact of Water Movement from Sewage and Settling Ponds Near a Potential High Level Radioactive Waste Repository in Yucca Mountain, Nevada, SAND91-0792, Sandia National Laboratories, Albuquerque, New Mexico.

Sobolik, S. R. and M. E. Fewell, 1993. Estimations of the Extent of Migration of Surficially Applied Water for Various Surface Conditions Near the Potential Repository Perimeter, SAND92-2248, Sandia National Laboratories, Albuquerque, New Mexico.

Sobolik, S. R., C. K. Ho, E. T. Dunn, T. H. Robey, and W. T. Cruz, in prep. Sensitivity of Hydrological Performance Assessment Analyses to Variations in Material Properties, Conceptual Models, and Ventilation Models, SAND94-0779, Sandia National Laboratories, Albuquerque, NM.

South, D. L. and J. J. K. Daemen, 1986. Permeameter Studies of Water Flow Through Cement and Clay Borehole Seals in Granite, Basalt, and Tuff, NUREG/CR-4748, Technical Report to the U. S. Nuclear Regulatory Commission, Division of Engineering Safety, Office of Nuclear Regulatory Research, by the Department of Mining and Geological Engineering, University of Arizona, Tucson, Arizona.

Spaulding, W. G., 1983. Vegetation and Climates of the Last 45,000 Years in the Vicinity of the Nevada Test Site, South-Central Nevada, USGS-OFR-83-535, Open-File Report, U.S. Geological Survey, Denver, Colorado.

Stahl, D., 1993. Interoffice Correspondence from D. Stahl (Civilian Radioactive Waste Management System Management and Operating Contractor) to R. Memory and S. Saterlie (Civilian Radioactive Waste Management System Management and Operating Contractor), June 21, 1993, regarding waste package corrosion inputs.

REFERENCES (Continued)

Stout, R., H. Leider, H. Weed, S. Nguyen, W. McKenzie, S. Prussin, C. Wilson, and W. Gray, 1990. Spent Fuel Waste Form Characteristics: Grain and Fragment Size Statistical Dependence for Dissolution Response, UCRL-JC-104931, Lawrence Livermore National Laboratory, Livermore, California.

Stout, R. in prep. Preliminary Waste Form Characteristics Report Version 1.0, UCRL-ID-108314, Lawrence Livermore National Laboratory, Livermore, California.

Subramanian, C. V., J. L. King, D. M. Perkins, R. W. Mudd, A. M. Richardson, J. C. Calovini, E. Van Eeckhout, and D. O. Emerson, 1990. Exploratory Shaft Seismic Design Basis Working Group Report, SAND88-1203, Sandia National Laboratories, Albuquerque, New Mexico.

Tait, C. D. et al., in prep. Report on Neptunium Speciation by NMR and Optical Spectroscopies, Los Alamos National Laboratory, Los Alamos, New Mexico.

Tidwell, V. C., in prep. Laboratory Investigation of Constitutive Property Scaling Behavior, SAND94-1745C, Sandia National Laboratories, Albuquerque, New Mexico.

Triay, I. R., in prep. Interim Report on Radionuclide Sorption/Whole Rock M3, Los Alamos National Laboratory, Los Alamos, New Mexico.

Tucci et al., in prep. Water Levels in the Yucca Mountain Area, Nevada, 1990-91, U.S. Geological Survey, Denver, Colorado.

Ueng, T. S. and W.J. O'Connell, 1992. Diffusion Releases Through One and Two Finite Planar Zones from a Nuclear Waste Package, UCRL-ID-10921, Lawrence Livermore National Laboratory, Livermore, California.

Ueng, T. S. and W.J. O'Connell, 1994. "Diffusion Releases Through One and Two Finite Planar Zones from a Nuclear Waste Package," Nuclear Technology, Vol. 108, p. 80.

Umari, A.M.J., A. Geldon, G. Patterson, J. Gemmel, J. Earle, and J. Darnell, 1994. "Use of an Analog Site near Raymond, California, to Develop Equipment and Methods for Characterizing a Potential High-Level Nuclear Waste Repository Site at Yucca Mountain, Nevada," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 2413-2422.

Valentine, G. A. and Groves, in prep. Entrainment of Country Rock during Basaltic Eruptions of the Lucero Volcanic Field, New Mexico, Los Alamos National Laboratory, Los Alamos, New Mexico.

REFERENCES (Continued)

Valentine, G. A. et al., in prep[a]. Use of Natural Analog and Modeling Techniques to Constrain the Effects of Magmatic Activity on Long-term Geologic Repositories, Los Alamos National Laboratory, Los Alamos, New Mexico.

Valentine, G. A., B. M. Crowe, F. V. Perry, in prep[b]. "Dikes vs. Sills in Shallow, Extensional Settings: Paiute Ridge, Nevada," submitted to Journal of Geophysical Research; also LA-UR-94-1805, Los Alamos National Laboratory, Los Alamos, New Mexico.

Vaniman, D. T., 1994. Calcite Deposits in Drill Cores USW G-2 and USW GU-3/G-3 at Yucca Mountain, Nevada: Preliminary Report, LA-12720-MS, UC-814, Los Alamos National Laboratory, Los Alamos, New Mexico.

Vaniman, D. T. and J. F. Whelan, 1994. "Inferences of Paleoenvironment from Petrographic, Chemical and Stable-Isotope Studies of Calcretes and Fracture Calcites, in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 2730-2737.

Vaniman, D. T. et al., in prep. Petrography, Mineralogy, and Chemistry of Calcite-Silica Deposits at Exile Hill, Nevada, in Comparison with Local Spring Deposits, Los Alamos National Laboratory, Los Alamos, New Mexico.

Ward, D. B. and M. D. Siegel, in prep. Carbonate-Enhanced Adsorption of NI(II) onto Geothite and Sand, SAND94-1756A, Sandia National Laboratories, Albuquerque, New Mexico.

Wells, D. L. and K. J. Coppersmith, in prep. "New Empirical Relationship Among Magnitude, Rupture Length, Rupture Area, and Surface Displacement," prepared for Bulletin of the Seismological Society of America, U.S. Geological Survey, Denver, Colorado.

Whelan, J. F., D. T. Vaniman, J. S. Stuckless, and R. J. Moscati, 1994. "Paleoclimatic and Paleohydrologic Records from Secondary Calcite: Yucca Mountain, Nevada," in Proceedings of High Level Radioactive Waste Management Fifth Annual International Conference, Las Vegas, Nevada, May 22-26, 1994, American Nuclear Society, La Grange Park, Illinois, Vol. 4, pp. 2738-2745.

Wilson, M. L. and T. H. Robey, 1994. "Effect of Stratigraphic Uncertainty on Repository Performance," SPECTRUM '94, Atlanta, Georgia; also SAND94-1370C, Sandia National Laboratories, Albuquerque, New Mexico.

REFERENCES (Continued)

Wilson, M. L., J. H. Gauthier, R. W. Barnard, G. E. Barr, T. H. Robey, A. Schenker, C. A. Rautman and D. Guerin, 1994. Total System Performance Assessment for Yucca Mountain - SNL Second Iteration (TSPA 1993), SAND93-2675, Sandia National Laboratories, Albuquerque, New Mexico.

Wittwer, C. S. et al., in prep. Development of a Three-Dimensional Moisture Flow Model, Yucca Mountain, Nevada," Lawrence Berkeley Laboratory, Berkeley, California.

WoldeGabriel, G., D. E. Broxton, F. M. Byers, Jr., 1994. Mineralogy and Temporal Relations of Coexisting Minerals in Altered Tuffs and the Utility of Alkali Zeolites as Potential Low Temperature Dateable Minerals," LA-UR 94-1259, Los Alamos National Laboratory, Los Alamos, New Mexico.

WoldeGabriel, G., in prep. Ion Exchange and Dehydration, Experimental Studies of Clinoptilolite: Implications to Zeolite Dating, Los Alamos National Laboratory, Los Alamos, New Mexico.

Yang, I. C. et al., in prep. Porewater Extraction from Unsaturated Tuff Using Triaxial and One-Dimensional Compression Methods, U.S. Geological Survey, Denver, Colorado.

Yeh, G., 1994. User's Manual for LEHGC: A Lagrangian-Eulerian Finite-Element Model of Hydrogeochemical Transport Through Saturated-Unsaturated Media - Version 1.0, SAND93-7081, Sandia National Laboratories, Albuquerque, New Mexico.

Zelinski, W. P., in prep. Two-Dimensional Model of Rock Structural Indices Along the North Ramp, Yucca Mountain, Nevada, SLTR94-0002, Sandia National Laboratories, Albuquerque, NM.

Zimmerman, R. W. et al., in prep. Semi-Analytical Dual-Porosity Simulators for Unsaturated Flow in Fractured Rock, U.S. Geological Survey, Denver, Colorado.

CODES AND REGULATIONS

10 CFR Part 60 (Code of Federal Regulations), 1993. Title 10, "Energy," Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," U.S. Government Printing Office, Washington, D.C.

10 CFR Part 71 (Code of Federal Regulations), 1994. Title 10, "Energy," Part 71, "Packaging and Transportation of Radioactive Material," U.S. Government Printing Office, Washington, D.C.

10 CFR Part 72 (Code of Federal Regulations), 1994. Title 10, "Energy," Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste," U.S. Government Printing Office, Washington, D.C.

10 CFR Part 960 (Code of Federal Regulations), 1984. Title 10, "Energy," Part 960, "Nuclear Waste Policy Act of 1982; General Guidelines for the Recommendations of Sites for the Nuclear Waste Repositories," U.S. Government Printing Office, Washington, D.C.

10 CFR Part 1021 (Code of Federal Regulations), 1993. Title 10, "Energy," Part 1021, "National Environmental Policy Act Implementing Procedures," U.S. Government Printing Office, Washington, D.C.

APPENDIX G

Acronyms, Abbreviations, and Symbols

Acronyms, Abbreviations, and Symbols

ACNW	Advisory Committee on Nuclear Waste
BLM	Bureau of Land Management
CRWMS M&O	Civilian Radioactive Waste Management System Management and Operating Contractor
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FY	fiscal year
LLNL	Lawrence Livermore National Laboratory
Los Alamos	Los Alamos National Laboratory
M&O	Civilian Radioactive Waste Management System Management and Operating Contractor
NAS	National Academy of Sciences
NRC	U.S. Nuclear Regulatory Commission
NWTRB	Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management
Project	Yucca Mountain Site Characterization Project
QA	quality assurance
SCP	Site Characterization Plan
SNL	Sandia National Laboratories
USGS	U.S. Geological Survey
YMP	Yucca Mountain Site Characterization Project
YMSCO	Yucca Mountain Site Characterization Office

Scientific/Engineering Terms and Units

BP	before present
darcy	= $10^{-12}m^2$ (permeability)
gpm	gallons per minute
ka	kiloannum (thousand years ago)
Ma	megannum (million years ago)
pH	negative log of hydrogen ion concentration (acidity/alkalinity)
ppb	parts per billion
ppm	parts per million

Acronyms, Abbreviations, and Symbols (Continued)

Borehole Letter Designators

c	Hydrologic test hole
G	Geologic
GA	Geologic angle "exploratory hole"
GU	Geologic unsaturated zone
h	Horizontal drilled hole
H	Hydrologic Research Facility holes
J	Jackass Flats (water wells)
N	Neutron hole
NRG	North Ramp Geologic hole
p	Paleozoic or pre-Tertiary hole
RF	Repository Surface Facility hole
SD	Systematic Drilling hole
SRG	South Ramp Geologic hole
UE	Underground Exploratory
USW	Underground southern (Nevada) waste hole
UZ	Unsaturated zone hole
UZN	Unsaturated zone neutron hole
V	Volcanic hole
VH	Volcanic/hydrologic hole
WT	Water table hole

Thermomechanical Stratigraphic Designators

CHn	Calico Hills nonwelded
PTn	Paintbrush nonwelded
TCw	Tiva Canyon welded
TSw1	Topopah Spring densely welded devitrified lithophysal-rich tuff
TSw2	Topopah Spring densely welded devitrified lithophysal-poor tuff
TSw3	Topopah Spring basal vitrophyre

Trench Designators

BMT	Bare Mountain Trench
CF	Crater Flat
MWV	Midway Valley
NRT	North Ramp Trench
SCR	Stagecoach Road
SCF	Solitario Canyon fault

Pavement Designators

ARP-1	Antler Ridge Pavement 1

Metal Designators

ASTM	American Society for Testing and Materials
UNS	Unified Numbering System for Metals and Alloys

Acronyms, Abbreviations, and Symbols (Continued)

Metric Units

°C	degree Celsius
cm^3	cubic centimeters
cm	centimeter (= 10^{-2} m or 2.54 inches)
d	day
g	gram (= 0.3527 ounce)
h	hour
ha	hectare (= 2.48 acres)
Hz	hertz (cycles per second)
J	joule (kilogram-meter)
°K	degree Kelvin
kg	kilogram (= 10^3 grams or 2.2046 pounds)
km	kilometer (= 10^3 m or 0.6213 mile)
L	liter (= 0.2641 gallon)
MTU	metric tons of uranium
MTIHM	metric tons of initial heavy metal
m	meter (= 3.2808 feet)
mg	milligram (= 10^{-3}g)
mL	milliliter (= 10^{-3} L)
mm	millimeter (= 10^{-3} m)
µm	micrometer (= 10^{-6} m)
nm	nanometer (= 10^{-9} m)
Pa	pascal (also, MPa = megapascal, kPa = kilopascal)
S	siemens
s	second
V	volt
W	watt
kWh	kilowatt-hour
MWh	megawatt-hour
MWd	megawatt-day
GWd	gigawatt-day

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